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THE PUBESCENT CHARACTERISTIC OF RED CLOVER, *TRIFOLIUM PRATENSE*, AS RELATED TO THE DETERMINATION OF ORIGIN OF THE SEED[1]

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RED clover, *Trifolium pratense*, is composed of a great variety of ecotypes and biotypes of the two distinct forms, double cut and single cut, known generally in the United States as medium red clover and mammoth red clover, respectively. The development of these types has been and is still being rapidly facilitated because red clover is for all practical purposes self sterile, and is, therefore, in a hybrid condition. Whenever one or more factors of the environment, such as diseases or insects, adversely affect the plants either by killing outright or reducing their growth to the point of impairment of seed production, the susceptible types are eliminated rapidly. The less adverse factors of the environment, such as different photoperiods, change the type more gradually.

Red clover is one of the most widely used legumes throughout Europe and the United States, but it is not indigenous to the United States, having been introduced from Europe by the early settlers. Since that time, depending upon the environment, many domestic ecotypes and biotypes have developed, distinguishable only when grown in the field, under selective environmental influences. Of particular interest in connection with the subject of this paper has been the development in the United States and Canada of a red clover form in which the pubescence is attached at right angles to the stems and leaf petioles and which may be descriptively called rough pubescence. On the European agricultural forms the pubescence is generally appressed but the plants are commonly classified as being smooth. (Figs. 1, 2, and 3.) Since American red clover is of European origin, it has been suggested by Pieters (1)[3] that the rough pubescent characteristic of American red clover has resulted from the survival of the segregates possessing this characteristic when the plants were sub-

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[2]Senior Agronomist. Grateful acknowledgment is made to W. A. Davidson, Enforcement of the Federal Seed Act, Agricultural Marketing Service, U. S. Dept. of Agriculture, for facilities and assistance in conducting this study.

[3]Figures in parenthesis refer to "Literature Cited", p. 10.

jected to infestations of the potato leafhopper, *Empoasca fabae*. In comparative trials this leafhopper has shown a marked preference for the European forms.

FIG. 1.—Types of pubescence on flowering stems of red clover plants. Stem on left European form, stem on right American form. (Magnified.)

The amount of pubescence varies greatly in any population of red clover plants, but in general, the American forms are much more pubescent than the European. With an increase in age of the stem and leaf petiole tissue and exposure to climatic conditions, such as rain and wind, it is believed that the pubescence becomes more brittle and either breaks off or aborts. Examinations of populations of wild red clover plants, representing the prototype of red clover, have revealed considerable variation between individual plants with regard to pubescence. Whether wild red clover or the rough pubescent plants less frequently found in the present European forms were the prototype of the American forms early records have not revealed.

Since 1922, hundreds of lots and varieties of red clover representing many different ecotypes and biotypes of European, domestic, and Canadian sources have been studied with regard to their adaptation in the principal red clover belt of the United States. In connection with this investigation, observations on populations of the agronomic European forms have shown that, in general, over 90% of the plants have appressed pubescence. Without critical inspection, many of these appear glabrous but upon closer scrutiny are seen to have a few trichomes or hairs. On the other hand, populations of plants of domestic sources grown in this country for many years without the admixture of other types, generally have less than 10% of plants with appressed pubescence. Similar results were obtained when seedling plants grown in the greenhouse from European and American seed were examined.

From an examination of cultivated and wild Norwegian types of red clover, Wexelsen (2) showed that 4% of the plants of the wild red clover had pubescence standing at right angles to the stem, while 77% of the plants had a relatively small amount of appressed pubescence. Of the cultivated races 1.4% of the plants were roughly pubescent and 88% appressed. Williams (3), in a study of the pubescence of red clover, found that 98% of the plants of American single cut or mammoth had rough pubescence, while only 10% of the Montgomery variety (English single cut, one of the most pubescent European varieties) had rough pubescence. In addition to the difference in position of the pubescence between the American and European forms, repeated observations of large populations have shown an apparent though less marked difference in the form of the tips of mature leaflets. Those of the European forms are more curved or keel-shaped than the leaflet tips of the American forms.

Agronomic forms may be classified into four general groups, American double cut, European double cut, American single cut, and European single cut. Seed of these forms is indistinguishable. The plants of each may be readily recognized, however, if grown to maturity, with the exception that the later-maturing double cut varieties and strains are somewhat similar to the early-maturing single cuts. Under normal light conditions, the single and double cut forms cannot be distinguished in the early seedling stage. Studies by Chmelar and Mostovoj (4) and by Itzerott (5), however, indicate that by the use of continued illumination, a large proportion of the plants of the double cut forms began to develop flowering stems 15 to 21 days after

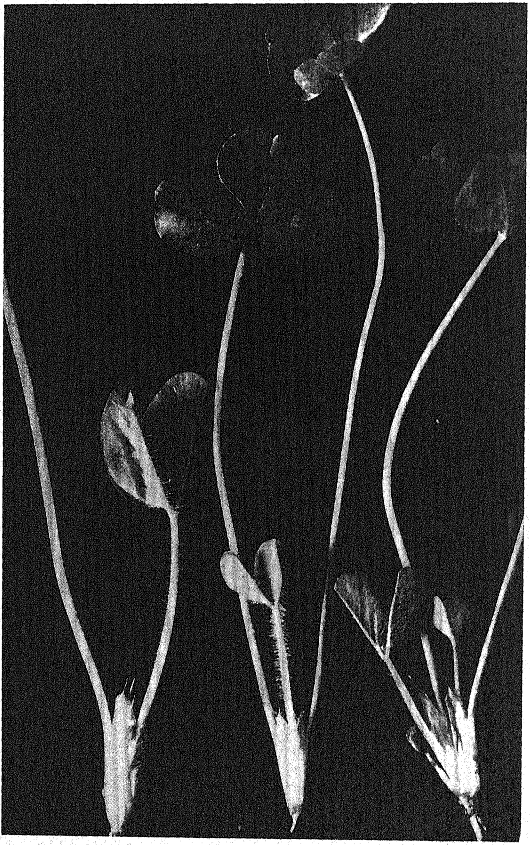

FIG. 2.—Type of pubescence of leaf petioles of seedling plants of the American form of red clover. (Natural size.)

germination, whereas, the development of the flowering stem in the single cut forms was much delayed. Considerable variation existed within every variety or lot studied indicating a lack of homozygosity for this character.

With the development of international commerce during the last 30 years, large quantities of red clover seed have been imported into the United States. Red clover seed has been handled as a commodity rather than as a living genetic entity and without regard to the adaptation of the plants to the environment where used. The seeds have

FIG. 3.—Type of pubescense on leaf petioles of seedling plants of the European form of red clover. (Natural size.)

been mixed and blended in accordance with the practices of the seed trade. The plants from such seed have been cross pollinated, thus combining the undesirable with the desirable characteristics. The level of adaptation of the crop has been decreased resulting in lower productivity and in many instances in complete losses. The movement of domestic red clover seed from a section where a certain strain is adapted to another where it is not so well adapted may also result in lower yields and losses in stand.

Since the European forms of red clover are not adapted to the principal part of the red clover belt of the United States, and since seed of the various forms cannot be distinguished, it seemed desirable to find a method more rapid than the field growing of all lots to determine the presence of the different forms. It is believed that the study here reported offers such a method.

In the enforcement of the federal seed act, samples are drawn from all imported lots of red clover seed and tested for germination and purity. In the winter of 1937–38, A. F. Musil found European weed seeds in several Canadian importations which raised the question as to the origin of the seed. Representative lots of Canadian-grown seed previously studied were of the American form resembling that grown in the United States, and if seed of Canadian and European forms has been mixed, or if pure European seed has been substituted, early confirmation of that fact would be desirable. In cooperation with those engaged in the enforcement of the federal seed act, greenhouse plantings, chiefly of the Canadian importations, were made in the fall and winter of 1938–39. The 122 lots of Canadian red clover seed studied represented importations made mostly during the period when the Canadian government had revoked the regulation requiring the staining of red clover seed imported from Great Britain. Seed imported into Canada from Great Britain during that period could have been blended with or substituted for Canadian seed and imported into the United States without being detected other than through the presence of European weed seed not common to the Canadian flora. Two hundred seeds of each lot were planted in flats 3 x 12 x 18 inches, spacing the rows 1½ inches apart and the seed ¾ of an inch apart in the row. When the plants were from 4 to 6 inches tall they were dug and each one classified as to the character of the pubescence. New growth or young tissue provides the most suitable part of the plant for observing this characteristic. The time of observation after planting varied from 6 weeks to 3 months, depending upon the date when sown. Growth was particularly slow when plantings were made during the winter solstice or when much cloudy weather prevailed, but facilities did not permit increasing the day length. The plants were classified into three groups, *viz.*, rough pubescence, appressed pubescence, and doubtful. Plants were recorded as doubtful when the pubescence was of such nature that it could not be accurately classified. In making the classification, experience gained from the observation of large populations of plants differing in pubescence is necessary to an accurate evaluation of the character of the pubescence. This is particularly true when young seedlings are examined, as the leaf petioles of the older leaves are less pubescent than the younger.

DISCUSSION

The results of this study as given in Fig. 4 show the value of the type of the pubescence of seedling plants in determining the origin of red clover seed. Of the 122 Canadian importations studied, 89, or 83.7%, produced plants with rough pubescence and may therefore be considered representative of American single or double cut forms. Twenty-one lots, or 17.2%, contained from 10 to 20% of forms with appressed pubescence, while the remaining 12 lots, or 9.1%, produced plants with very significant percentages which were definitely of European forms not adapted to the principal red clover belt of the United States. Of the plants from the 122 Canadian lots, those on which the type of pubescence was doubtful amounted to an average of approximately 3% with a range from zero to 10%. The few lots of

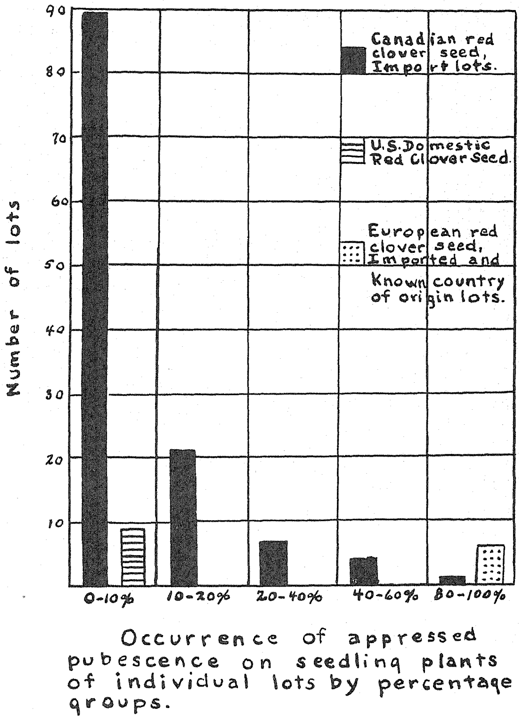

FIG. 4.—Results of greenhouse studies on the classification of seedling plants for appressed pubescence from imported Canadian red clover seed, U. S. domestic red clover seed, and European red clover seed from imported and known country of origin lots, Washington, D. C., 1938–39.

domestic and European seed, included in these studies for comparative purposes in recording the classifications, are not representative of the variation that may be expected from an investigation of a large number of lots of commercial seed.

The results of a preliminary experiment in which artificial mixtures of American and European forms were made in varying percentages of each by weight are interesting. Considering seed size and labora-

tory germination of the original samples, the same relative proportions of the two forms were recovered when the seedling plants were classified on the pubescent characteristic.

These results, without the supporting evidence presented in the next section, should not be interpreted to mean that European clover seed was mixed with Canadian red clover seed before importation into the United States. While it may be true that such was the case, it is possible that the European forms had been grown in Canada for one or more generations and the resulting progenies could be legally classified as Canadian seed even though the lots contained varying amounts of the European forms.

After this problem was called to the attention of the Canadian authorities, every effort was made by them to insure that each lot of seed exported to the United States was the product of Canadian grown seed and that such seed was accompanied by an official Canadian certificate. Since September 15, 1938, the Canadian Government has required that all seed of European sources other than Italian be stained green before admission into Canada. This should eliminate the direct mixing of European seed with Canadian seed, but does not obviate the presence of European forms in Canadian seed after such seed is grown for one or more generations in Canada.

Furthermore, it is of interest in connection with this problem to know that the Altaswede variety, a selection of Swedish single cut red clover with appressed pubescence developed at the University of Alberta, is rather widely used in western Canada and the imported lots containing the European forms may represent this variety or mixtures thereof.

The finding of European forms is not unexpected, since these forms have been grown elsewhere in Canada and undoubtedly harvested for seed. When European forms are imported into the United States a similar condition prevails here for during the years when the environmental factors, adverse to the European forms, are not severe, survival often occurs and a partial seed crop may be obtained. Seed harvested from a 40-acre field of European double cut red clover grown in central Illinois produced a similar proportion of plants with appressed pubescence as the plants from seed imported direct from Europe.

Furthermore, in some sections of the Pacific Northwestern States the European forms are nearly as productive as the American forms and if seed of the European forms is used, a similar problem exists in regard to the presence of European forms in domestic seed.

It is not known how long the European forms or segregates from hybridization between the American and European forms will persist when grown under environmental conditions to which they are not adapted. While preliminary studies on the inheritance of the position of the pubescence of red clover have been attempted the parental material was not homozygous for this characteristic and the readings of the F_2 population were indefinite.

WEED SEED IN EUROPEAN RED CLOVER SEED

The presence of European weed seed in imported red clover seed presents an interesting question as to the origin of the red clover seed. If the most common European weed seeds found in imported European red clover seed are not found in numerous lots of red clover seed known to have been grown in the United States and Canada, empirical evidence would indicate that the European red clover seed has been mixed with the domestic and Canadian seed and had not originated as first generation seed from previous plantings. In adaptation and yield investigations of hundreds of lots of imported European red clover seed containing varying percentages of European weed seed, plants of these weed species have not been observed growing in the plots either the first or second year after planting.

In a preliminary study in cooperation with the Division of Seed Investigations, a sample of Canadian imported red clover was selected and to this was added a known quantity of weed and other crop seeds which appear as common impurities in European grown red clover seed, namely, *Picris echioides*, *Anagallis arvensis*, *Reseda* sp., *Galeopsis ladanum*, *Scleranthus annuus*, *Carduus acanthoides*, *Centaurea* spp., *Torilis* spp., *Delphinium* sp., and *Lotus corniculatus*. The weed seeds were separated from other imported samples of European red clover seed and added to the original sample to provide a greater percentage of weed seed for determining whether the weed seed would produce plants that would reproduce when sown with the red clover seed.

The sample was divided and seeded in small plots at Ithaca, New York; Madison, Wisconsin; Lexington, Kentucky; and Urbana, Illinois, in the spring of 1938. Frequent observations on the flora of these plots were made throughout the first and second season. Germination tests were not conducted on the weed seed so the viability was not known; however, as previously mentioned, most of the seed was from several imported lots of red clover seed, and represents the European weed seed which normally occurs in the importations.

The results of these plantings are as follows: At Lexington, Kentucky, plants of none of the species included in the sample were found during the first or second year; at Urbana, Illinois, one plant of *Lotus corniculatus*, and at Ithaca, New York, one plant each of *Picris echioides* and *Lotus corniculatus* were found the second year, while at Madison, Wisconsin, two plants of *Picris echioides* were found in the fall of the first year. These plots were plowed in the fall of the first year and the survival the second year could not be determined.

The analysis of the weed seed content of the 122 lots of imported Canadian seed at time of entry into the United States by A. F. Musil of the Division of Seed Investigations resulted in 11 lots that were considered questionable as to source of origin because of the presence of European weed seed.

The appressed pubescence of the seedling plants of these same lots in the greenhouse studies with the same classification as used in Fig. 4 are as follows: One lot in the 80–100 percentage group, four lots in the 40–60 percentage group, five lots in the 20–40 percentage group, and one lot in the 10–20 percentage group. Referring to Fig. 4,

it may be seen that these questionable lots comprise all but two of the lots having 20% or more of appressed pubsecent plants.

From extensive examinations of samples of Canadian red clover seed, Musil (6) reports that certain weed seeds characteristic of European red clover are not found in Canadian red clover seed and this is further substantiated by the significant fact that European weed seeds were not found in the 89 samples in which the number of seedlings having appressed pubescence fell into the class of 0 to 10% group and only 1 out of 21 lots of the 10 to 20% group contained European weed seed. The striking relationship between the presence of European forms and the presence of European weed seed in these lots and the apparent fact that characteristic European weeds of imported red clover seed are not found in Canadian and domestic red clover seed would indicate that European seed had been mixed with Canadian seed and in the case of one lot substituted for Canadian seed. It would seem that further studies of the weed flora of the red clover seed producing sections of Canada, and ecological and life history studies of the principal European weeds found in European red clover seed not found in Canadian and United States grown seed, will contribute to a solution of this problem.

The importation of European forms of red clover unadapted in the United States is one means by which the productivity of red clover is lowered and it is of little wonder that red clover failures become more frequent and that the potentialities of a valuable crop are reduced.

CONCLUSIONS

The results of these studies indicate that the seedling plants of European forms of red clover having appressed pubescence can be distinguished from the rough pubescent American forms in greenhouse plantings and that this affords a method suitable for rapid analysis to determine the proportion of each form in a sample of red clover seed.

The identification of European forms in imported lots of Canadian red clover seed of itself would not necessarily mean that European red clover seed had been mixed or blended with Canadian seed before importation. The presence of characteristic European weed seed in imported Canadian red clover seed lots containing a high percentage of European forms of red clover does appear to indicate that in some cases European red clover seed has been blended with or substituted for Canadian grown seed.

This conclusion seems justified since characteristic European weed seeds found in European red clover seed are not found in samples of red clover seed grown in the United States and Canada.

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HYBRIDIZING OATS TO COMBINE GROWTH FOR WINTER PASTURE, HARDINESS, AND RESISTANCE TO RUSTS AND SMUTS[1]

H. R. ROSEN, L. M. WEETMAN, AND C. K. McCLELLAND[2]

ONE of the important agricultural problems of Arkansas and the South as a whole is concerned with a frequent shortage of home-grown feed for livestock, particularly during the winter months. (There is also a shortage of livestock.)

To meet this problem, the breeding of oat varieties which would combine hardiness and good winter growth with resistance to rusts and smuts appeared exceptionally promising. The outstanding work of Stanton, Murphy, Coffman, and Humphrey[3] of the U. S. Dept. of Agriculture, in which they were able to combine resistance to crown rust, stem rust, and smuts in oats, made it immediately possible to obtain from them varieties possessing these characters and to cross them with others which possessed either hardiness or made good winter growth.

The commercial varieties of oats available at present for fall sowing, or so-called winter oats, fall into one of two groups, *viz.*, the red oat group represented mainly by Red Rustproof and its numerous derivatives, and a mixed lot in which Winter Turf, Hairy Culberson, Coker's 32-1, Lee, and Custis are common representatives. The Red Rustproof group may be characterized as making fair or mediocre winter growth, possessing slight hardiness, but capable of escaping crown rust to a considerable degree, (under natural conditions but not in the greenhouse), and also showing some degree of resistance to smuts. The varieties mentioned in the mixed lot, with the exception of Coker's 32-1, do not make much winter growth, but are much hardier than the Red Rustproof group. Unfortunately, these hardy oats are all very susceptible to the races of crown rust common in the South.

So far as hardiness is concerned, in addition to the varieties mentioned, N. I. Hancock of the Tennessee Agricultural Experiment Station and C. B. Cross of the Oklahoma Agricultural Experiment Station have made valuable selections from Winter Fulghum 2499 and from a U. S. Dept. of Agriculture hybrid, Hairy Culberson × Winter Fulghum. Some of these selections have shown even greater hardiness than any other variety tested.

In beginning the breeding work in 1936, the present writers attempted to gather all of the most important varieties which possessed either resistance to parasites, hardiness, or were of promise in making good winter growth, and to hybridize in an effort to combine all of these characters.

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[1]Research paper No. 655, Journal Series, University of Arkansas, Fayetteville, Ark. Received for publication October 6, 1939. Published with the approval of the Director of the Arkansas Agricultural Experiment Station.

[2]Professor of Plant Pathology, Instructor of Plant Pathology, and Assistant Professor of Agronomy, respectively.

[3]STANTON, T. R., MURPHY, H. C., COFFMAN, F. A., and HUMPHREY, H. B. Development of oats resistant to smuts and rusts. Phytopath., 24:165-167. 1934.

To N. I. Hancock and C. B. Cross and particularly to T. R. Stanton, H. C. Murphy, and C. R. Adair, the writers are very greatly indebted for furnishing seeds of their own valuable selections and hybrids, none of which were on the market and some of which had not been described. The generosity of these investigators made it possible to bring together probably the most promising group of oats that has been available up to the present, particularly from the standpoint of breeding to combine resistance to parasitic diseases with winter growth and hardiness. Without their cooperation, no such breeding could have been possible.

The paradox of attempting to combine hardiness with winter growth seemed rather questionable in the face of a considerable body of evidence indicating a lack of or reduction in hardiness when plants are in a growing condition. Nevertheless, since hardiness under Arkansas conditions requires a plant capable of growing under relatively mild winter temperatures interspersed between sharp drops of short duration, it appeared desirable to attempt such a combination.

Working in a greenhouse during the winter of 1936–37, the writers emasculated and pollinated 6,045 oat florets and obtained 984 seeds. Approximately one-third of these seeds failed to germinate, but over 600 F_1 hybrids were grown with sufficient seeds obtained from each plant to enable planting in most instances several rod rows outdoors in the fall, and also some in the greenhouse. All of the seeds from the F_1 plants were artificially inoculated with loose and covered smut of oats. The F_2 plants grown in the greenhouse were artificially inoculated with race 1, the most common and destructive race of crown rust found in Arkansas. All plants found susceptible to either crown rust or smut were discarded, and seeds were saved from the remaining plants.

In the field, several thousand F_2 plants survived the winter of 1937–38. Since check plantings of standard varieties and of hardy parents space-planted as were the hybrids, suffered very marked reduction in stand during this winter, some with a complete killing of all the plants, it appeared that the surviving hybrids possessed hardiness. The crown rust resistant varieties Bond and Victoria were completely killed, while all of the strains of Red Rustproof included in the tests showed very marked reduction in stand. Ferguson 922, for example, was reduced to a stand of 6.5%. Subsequent hardiness tests in the F_3 generation suggest that some of the hybrids possess as much hardiness as the hardiest parents.

The progeny of these hybrids are now in the F_4 and F_5 generations. Field tests during the past year, 1938–39, at the main experiment station at Fayetteville and at the rice branch station at Stuttgart indicate a relatively large number of hybrid selections capable of making one and a half to several times as much winter growth as the original parents or as the best of the commercial varieties. There is also promise that resistance to the diseases designated above has been combined with hardiness and ability to make winter growth. On the other hand, in some of the hybrids there are indications that good grain characters have not been combined with other desirable properties, particularly with good winter growth. This, however, does not

appear to be true for all hybrids. Some of the more promising hybrids consist of the following:

Coker's 32–1 × Victoria and its reciprocal
Coker's 32–1 × (Victoria × Richland) and its reciprocal
Tennessee 1884 × Bond
Tennessee 1884 × (Bond × Iogold)
Tennessee 1922 × Bond
Tennessee 1922 × (Victoria × Richland) and its reciprocal
Tennessee 1922 × (Bond × Iogold)
Tennessee 1922 × (Fulghum × Victoria)
Fulghum 3232 × Bond
Lee × (Victoria × Richland) and its reciprocal
Lee × (Bond × Iogold)
Lee × (Fulghum × Victoria)
Custis × (Bond × Iogold) and its reciprocal
Hairy Culberson × Bond
Hairy Culberson × (Bond × Iogold)
Coker's Fulgrain 33–19 × (Victoria × Richland)
Coker's Fulgrain 33–19 × (Bond × Iogold)
Victoria × Custis
Victoria × Coker's Fulgrain 33–19
(Victoria × Richland) × (Hairy Culberson × Fulghum) Oklahoma 2900
(Victoria × Richland) × Hairy Culberson
(Bond × Iogold) × Coker's 32–1
(Bond × Iogold) × Tennessee 1945
(Fulghum × Victoria) × (Bond × Iogold)
(Hairy Culberson × Fulghum) Oklahoma 2900 × Victoria
(Hairy Culberson × Fulghum) Oklahoma 2900 × (Bond × Iogold)
(Lee × Bond) × Fulghum 3232
(Lee × Bond) × (Fulghum × Victoria)

Some 8,000 individual plant selections from these and other hybrids are now being grown at two stations in Arkansas and seeds from a few of the hybrids have been made available to other investigators. It is quite likely that small quantities of seeds will be available for additional distribution in the summer of 1940. It is to be noted that while some of the hybrids now appear to be homozygous for resistance to rusts and smuts and for winter growth and hardiness, a relatively large number are still segregating. It may also be noted that, while the chief emphasis has been placed on breeding for much-needed winter forage, and that grain characters have also been considered nevertheless no immediate recommendations are possible because of insufficient data. It can be said, however, that some of the hybrids are quite promising.

THE DURATION OF THE EFFECTS OF RENOVATION IN THE CONTROL OF WEEDS AND WHITE GRUBS (*PHYLLOPHAGA* sp.) IN PERMANENT BLUEGRASS PASTURES[1]

F. V. Burcalow, D. W. Smith, and L. F. Graber[2]

THE establishment of the dry-weather legumes, sweet clover (*Melilotus alba*, or *Melilotus officinalis*), alfalfa (*Medicago sativa*), and red clover (*Trifolium pratense*), in permanent bluegrass pastures for the purpose of improving them without plowing, has been developed by Graber (1, 2, 3),[3] and is designated as renovation. Papers have also been published by Fuelleman and Graber (4, 5) showing the effectiveness of this method of pasture improvement in the control of weeds and white grubs during periods of 1, 2, and 3 years after the legumes were established. Additional data were gathered in 1939 by the quadrat method which show further duration of the residual benefits of renovation in terms of the reductions in weed and white grub populations, as well as to indicate the principal factors on which the duration of such benefits rest. These studies were made in 1939 on 14 of the 30 permanent bluegrass pastures where portions of from 1 to 33 acres had been renovated in 1934 and 1935, and on which studies of weed and white grub populations were made by Fuelleman and Graber (4, 5) in 1935–36 and 1937.

PREVIOUS STUDIES

In 1937, the total weed populations (5) of the renovated portions of the 30 pastures were 85.8% less than the weed populations of the adjacent areas of unrenovated bluegrass. The populations of white grubs (4) as determined by counts made in 1935–36, were 98% less in the portions of 15 pastures renovated in 1934, and 91% less in the portions of the 15 pastures renovated in 1935, than in adjacent areas of unrenovated bluegrass of equal area.

In 1939, 7 of the 15 pastures where a portion of each was renovated in 1934 and 7 of the 15 pastures where a portion of each was renovated in 1935, were selected on the basis of their distribution in southwestern Wisconsin, for further study of the weed and white grub populations using the same methods of determination.

The weed counts in 1937 and the grub counts in 1935–36 on the renovated and unrenovated portions of these 14 pastures are shown in Tables 1 and 2. As previously indicated, these pastures were studied again in 1939 and in the tabulations, they are divided into two groups. One group of nine pastures was grazed moderately, or cut for hay, or both, and the other group of five pastures was grazed excessively.

[1]Contribution No. 147 from the Department of Agronomy, University of Wisconsin, Madison, Wis. Published with the approval of the Director of the Wisconsin Agricultural Experiment Station. Received for publication October 5, 1939.

[2]Instructor, Assistant, and Professor of Agronomy, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 22.

TABLE 1.—*Total numbers of weeds per acre in the renovated portions of each of 14 pastures renovated in 1934 and 1935 and in adjacent portions of each not renovated.*

Pasture No.	When renovated	No. of weeds per acre on unrenovated and renovated portions					
		1937			1939		
		Not renovated	Renovated	% reduction	Not renovated	Renovated	% reduction
		Grazed Moderately, or Cut for Hay, or Both					
1	June 12, '34	674,000	88,000	86.9	322,000	6,000	98.1
4	June 11, '34	930,000	182,000	80.4	300,000	6,000	98.0
6	May 4, '34	716,000	58,000	91.9	286,000	50,000	82.5
7	May 17, '34	994,000	54,000	94.6	964,000	146,000	84.9
10	May 8, '34	1,478,000	374,000	74.7	632,000	16,000	97.5
16	June 1, '35	1,876,000	448,000	76.1	304,000	28,000	90.8
18	May 9, '35	994,000	290,000	70.8	182,000	8,000	95.6
20	May 25, '35	928,000	322,000	65.3	832,000	30,000	96.4
23	May 21, '35	652,000	44,000	93.3	68,000	2,000	97.1
Average..........		1,026,889	206,667	79.9	432,222	32,444	92.5
		Grazed Excessively					
5	May 28, '34	1,316,000	108,000	91.8	238,000	98,000	58.8
12	May 3, '34	702,000	110,000	84.3	46,000	24,000	47.8
19	June 7, '35	510,000	110,000	78.4	432,000	122,000	71.8
21	May 16, '35	1,264,000	158,000	87.5	250,000	180,000	28.0
28	Mar. 20, '35	1,408,000	54,000	96.2	282,000	152,000	46.1
Average..........		1,040,000	108,000	89.6	249,600	115,200	53.8

In the nine pastures grazed moderately, or cut for hay, or both, renovation reduced the weed populations 79.9% in 1937 and the white grub populations 98.3% in 1935–36. In the five pastures grazed excessively, renovation reduced the populations of weeds 89.6% in 1937 and of white grubs 95.8% in 1935–36. In 1939, however, the residual benefits of the renovations of 1934 and 1935 as measured on the basis of the control of the two common pests of the permanent grasslands of Wisconsin was dependent primarily on the managerial treatments of the renovated and unrenovated portions of each pasture.

RESIDUAL BENEFITS IN 1939 FROM 14 RENOVATIONS OF 1934 AND 1935

Where moderate grazing was practiced on the unrenovated portions of nine pastures and where the adjacent renovated areas were grazed moderately, or cut for hay, or both, in the years following the establishment of the legumes, the renovations of 1934 and 1935

(Tables 1 and 2) reduced the weed populations in 1939, 92.5% and the white grub populations 75.2%.

TABLE 2.—*Total numbers of white grubs per acre in the renovated portions of each of 14 bluegrass pastures renovated in 1934 and 1935 and in adjacent portions of each not renovated.*

Pasture No.	When renovated	No. of white grubs per acre on unrenovated and renovated portions					
		1935–36			1939		
		Not renovated	Renovated	% reduction	Not renovated	Renovated	% reduction
		Grazed Moderately, or Cut for Hay, or Both					
1	June 12, '34	55,757	0	100.0	62,000	2,000	96.8
4	June 11, '34	34,848	0	100.0	62,000	2,000	96.8
6	May 4, '34	142,000	0	100.0	118,000	42,000	64.4
7	May 17, '34	232,000	0	100.0	126,000	60,000	52.4
10	May 8, '34	292,000	4,000	98.6	160,000	2,000	98.8
16	June 1, '35	172,008	4,356	97.5	82,000	26,000	68.3
18	May 9, '35	214,000	8,000	96.3	232,000	34,000	85.3
20	May 25, '35	128,000	8,000	93.8	52,000	28,000	46.2
23	May 21, '35	154,000	0	100.0	148,000	62,000	58.1
Average		158,290	2,706	98.3	115,778	28,667	75.2
		Grazed Excessively					
5	May 28, '34	220,000	8,000	96.4	158,000	86,000	45.6
12	May 3, '34	0	0	0	78,000	62,000	20.5
19	June 7, '35	120,000	14,000	88.3	42,000	22,000	47.6
21	May 16, '35	330,000	8,000	97.6	182,000	28,000	84.6
28	Mar. 20, '35	156,700	4,356	97.2	86,000	30,000	65.1
Average		165,340	6,871	95.8	109,200	45,600	58.2

Where excessive grazing was practiced on both the renovated and adjacent unrenovated areas of five pastures, the renovations of 1934 and 1935 reduced the weed populations in 1939, 53.8% and the white grubs 58.2%. It is obvious that without judicious managerial treatments, the duration and efficiency of renovation in the improvement of bluegrass pastures is greatly curtailed.

Weeds were much less prevalent in the bluegrass pastures of southern and western Wisconsin in 1939 than in 1937. This was shown by general observations and is illustrated more specifically by the total populations (Table 1) in the unrenovated portions of the 14 pastures which were studied. They averaged over one million weeds per acre in 1937 when ragweeds (*Ambrosia artemisiifolia*) and horseweeds (*Erigeron canadensis*) were the dominant species, compared with less than a half-million in 1939 when ragweeds, as usual, were the dominant species.

With moderate grazing, the renovations were more effective in reducing weeds (92.5%) in 1939 than in 1937 when the reduction was 79.9%, but with excessive grazing the control of weeds in 1939 by the renovations of 1934 and 1935 was much less (89.6% in 1937 compared with 53.8% in 1939). Excessive grazing up to and including 1937 enhanced to some extent the degree of weed control (89.6%) resulting from the renovations when compared with moderate grazing (79.9%), but when excessive grazing was continued up to and including 1939, weed control was severely reduced.

While all the renovations resulted in a very high degree of white grub control (over 95%) in 1935–36 (Table 2), such control was reduced to 75.2% in 1939 under the managements designated as moderate grazing, or cut for hay, or both, and to 58.2% with excessive grazing. Managerial treatments had much to do with the duration of maximum benefits from renovations in white grub control. Because fewer dry-weather legumes prevailed in the renovated areas to repel the egg-laying June beetles in 1937 and 1938 than during the beetle flights three years previous (1934 and 1935), grub control in 1939 was to a very considerable extent due to the greater density of the sod of the renovated areas. In general, the densities of the grass sods were inversely correlated with the intensities of grazing.

VARIABILITY OF DATA

A comparison of the data (Tables 1 and 2) showing the degree and duration of the benefits of renovation in terms of weed and white grub control in each of the 14 pastures studied reveals a wide variability. Thus, the reduction of weeds in the five pastures grazed excessively varied from 28.0% (pasture No. 21) to 71.8% (pasture No. 19) in 1939. Likewise, the variability in white grub control ranged from 20.5% (pasture No. 12) to 84.6% (pasture No. 21) in 1939.

Since the 14 pastures were widely distributed in southern and western Wisconsin, and since the renovations were established on soils which differed widely in type, exposure, and fertility, and since a wide range in the amount of rainfall and other climatic factors prevailed, variability is to be expected. The averages are used merely to simplify the presentation and discussion of the data.

MANAGERIAL TREATMENTS

All the unrenovated portions of the 14 pastures under consideration were grazed annually with cattle. Most of the renovated portions were also grazed with the cattle, and in nearly all such instances the same cattle had "free choice" in the grazing of the renovated and unrenovated portions of each pasture. Invariably the cattle showed a definite preference for the grasses and legumes of the renovated portion and this was true particularly in the dry portions of the grazing season.

The legumes utilized for the renovations, and the grazing and cutting treatments following the year in which the legumes were established, are shown in Table 3. The nine renovations cut for hay, or used for hay and pasture, or grazed moderately, are placed in a group

in Tables 1 and 2 for the reason that the managerial practices applied to them and the adjacent areas not renovated were of such a character as not to weaken the grasses (predominately bluegrass) by lowering the food reserves, or otherwise. In contrast, the grasses of the five pastures grouped in Tables 1 and 2 as being grazed excessively were weakened by reductions in food reserves from the close early spring grazing and heavy pasturing throughout the entire growing season.

TABLE 3.—*Legumes established in the renovated portions of 14 permanent bluegrass pastures and the managerial treatments of the renovated areas following the year in which the legumes were sown.*

Pasture No.	When renovated	Legumes established*	Managerial treatments of renovated portions*				
			1935	1936	1937	1938	1939
1	June 12, '34	Alf., R. C.	Hay	Hay	H. & P.	H. & P.	H. & P.
4	June 11, '34	Alf., R. C.	Hay	Hay	Hay	Mod. gr.	Mod. gr.
6	May 4, '34	Sw. Cl.	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.
7	May 17, '34	Sw. Cl.	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.
10	May 8, '34	Alf., R. C., Sw. Cl.	Hay	Hay	Mod. gr.	Mod. gr.	Mod. gr.
16	June 1, '35	Alf., Sw. Cl.	———	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.
18	May 9, '35	Sw. Cl.	———	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.
20	May 25, '35	Sw. Cl.	———	Mod. gr.	Mod. gr.	Mod. gr.	Mod. gr.
23	May 21, '35	R. C., Alf.	———	H. & P.	H. & P.	H. & P.	H. & P.
5	May 28, '34	Alf., Sw. Cl.	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.
12	May 3, '34	Alf., Sw. Cl.	H. & P.	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.
19	June 7, '35	Alf., Sw. Cl.	———	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.
21	May 16, '35	Sw. Cl.	———	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.
28	Mar. 20, '35	Sw. Cl.	———	Ex. gr.	Ex. gr.	Ex. gr.	Ex. gr.

*Alf. = Alfalfa; R. C. = Red clover; Sw. Cl. = Sweet clover (biennial white); H. and P. = Hay and pasture; Mod. gr. = Moderate grazing; and Ex. gr. = Excessive grazing.

PERSISTENCE OF LEGUMES IN RENOVATED AREAS

A fairly good stand of alfalfa still prevailed in 1939 in the renovated portions of pastures Nos. 1 and 4 which had been cut for hay and grazed moderately, and a good stand of red clover persisted (by virtue of reseeding) in the renovated portion of pasture No. 23. A very good stand of seedling plants of biennial white blossom sweet clover prevailed (1939) in the renovated portions of pastures Nos. 6, 16, 18, 20, and 28, and likewise, a fairly good stand of young sweet clover and old alfalfa prevailed in the renovated portion of pasture No. 10. All but two of the pastures (Nos. 19 and 28) grazed excessively were devoid of the dry-weather legumes in 1939 which had been sown in the renovations of 1934 and 1935. A surprisingly good stand of seedling plants of sweet clover prevailed in the renovated area of pasture No. 19 and a fair stand in pasture No. 28. Alfalfa did not persist effectively after its establishment for more than 2 years under excessive grazing treatment.

The extent to which sweet clover which had been grazed so as to produce seed in its second year was able to re-establish itself depended

largely on a desirable content of lime, phosphate, and potash in the soil and on the density of the grass sods. The latter was greatly influenced by the grazing treatments, water retention of the soil, and nitrogen content.

MANAGEMENT AND PERSISTENCE OF SWEET CLOVER

Where sweet clover is grazed heavily for two or three weeks in early spring of its second year's growth and then allowed to recover and approach blossoming before grazing is resumed, much seed is usually formed despite moderately heavy grazing. If, after such seed formation very close grazing of the grasses is practiced for the remainder of the season, the grasses are weakened and their competition is sufficiently reduced, as a rule, to permit seedling plants to establish themselves the following spring. At times, the grasses of the renovated areas are again grazed closely the following spring before the sweet clover seedlings attain sufficient height to be injured by defoliation. Trampling is not very injurious unless the soil is well saturated with moisture. However, such early spring grazing can only be temporary, otherwise the seedling plants of sweet clover may be destroyed.

After about July 15 (in Wisconsin) when the seedling plants are well established, moderate grazing up to September 1, or thereabouts, is practiced without severe injury to the stand of young sweet clover. For the fall period, the plants are unmolested so that they can elaborate and store foods for the development of hardy rhizomes and for the survival of the over-wintering parts.

This method of grazing was not always practiced with respect to the renovations on which results are reported in this paper. However, where sweet clover reseeded itself abundantly the year after sowing and where the grass sods did not become too dense, the appearance of young sweet clover plants prevailed for one or more years in many of the renovations where sweet clover was sown.

Farmers are fast becoming cognizant of the economy in the utilization of sweet clover for pasture improvement. The soil is enriched with nitrogen and organic matter. Weeds and white grubs are greatly reduced, not only for the first two years after the renovation treatment, but in subsequent years as well. With judicious grazing and proper soil conditions, good stands of sweet clover may prevail for several years by virtue of reseeding. Of the three dry-weather legumes, sweet clover was by far the most aggressive in re-establishing itself by reseeding. Medium red clover was intermediate in this respect, but the reseeding of alfalfa was practically nil in these trials.

A RENOVATION IN 1929

The first outlying demonstration of pasture renovation in Wisconsin was established in 1929 with sweet clover on four acres of a steep hillside pasture located in southwestern Wisconsin near Mineral Point. The soil was in a low state of fertility. Ragweeds (*Ambrosia artemisiifolia*) and wild carrot (*Daucus carota*) were abundant in this pasture and the grasses were mostly Kentucky bluegrass and Canadian bluegrass. With applications of lime, phosphate, and potash, and

with proper scarification by disking and harrowing of the thin sod, and other desirable cultural treatments in 1929 (grazing was completely eliminated), an excellent stand of biennial white blossomed sweet clover was established. In 1930, this sweet clover and the grasses associated with it were grazed closely from May 10 to June 21. The cattle were removed on the latter date and grazing was not resumed until July 21, when the second growth of the sweet clover was fully 4 feet high and well blossomed. Although the sweet clover and grasses were grazed heavily from July 21 to November 1, a very heavy set of seed occurred in August and nearly all of it had fallen to the soil before winter. From 1931 to 1939, inclusive, the fence around the renovated portion was removed and the cattle had "free choice" as far as the grazing was concerned. Because they preferred the grasses and sweet clover of the renovated portion, it received more intensive grazing than the unrenovated portion of the pasture.

In southwestern Wisconsin the major flights (broods C and A) of egg-laying June beetles occurred in 1928 and 1929, 1931 and 1932, 1934 and 1935, and in 1937 and 1938. The years of severe damage from white grubs occurred in 1930, 1933, 1936, and 1939. In 1930, 220,000 white grubs per acre were found on the unrenovated portion of this pasture and only 20,000 on the renovated portion, a reduction of 90.9%. In 1933, this renovation continued to reduce grub populations from 180,000 to 23,000, or 87.2%; in 1936 from 118,000 to 24,000, or 79.7%; and in 1939, from 142,000 to 42,000, or 70.4%.

Weed counts were taken only in 1937, 1938, and 1939 when the total populations per acre were 2,554,000, 942,000, and 232,000 respectively, on the unrenovated portion compared with 162,000, 94,000, and 50,000 respectively, on the renovated portions. The reductions in weed populations were 93.7%, 90.0%, and 78.5%, respectively. The benefits from the renovation of 1929, as measured in terms of weed and white grub control, persisted to a very marked degree for a period of 10 years and this was largely due to conditions which made it possible for sweet clover to maintain itself effectively by reseeding in 1930 and re-establishment in 1931 and thereafter. New and dense stands of young seedling plants of sweet clover appeared in 1931, 1932, 1933, and in 1935, and they were grazed in such a manner as to assure a fairly good survival and dense second-year growths in 1932, 1934, and 1936. However, the sod became so dense after 1936 that the reseeding and the re-establishment of the sweet clover was greatly reduced.

Among the interesting vegetational changes which followed this renovation of 1929 was the disappearance of Canadian bluegrass (*Poa compressa*) and of wild carrot (*Daucus carota*) in the renovated portions of the pasture.

SUMMARY

The establishment of dry-weather legumes in permanent bluegrass pastures without plowing and without destroying the grasses is designated as renovation. While for the first two or three years after renovation, such treatment was very effective in controlling weeds and white grubs (*Phyllophaga* sp.), the two common pests of permanent

grasslands in southern and western Wisconsin, further duration of such benefits was dependent on managerial treatment. With moderate grazing or its equivalent, weeds were reduced 92.5% and white grubs 75.2% in 1939 on the portions of nine pastures renovated in 1934 and 1935, when compared with adjacent unrenovated portions of equal area. With excessive grazing on five pastures such weed reductions averaged 53.8% and the white grub control was only 58.2% in 1939.

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TOXIC LIMITS OF REPLACEABLE ZINC TO CORN AND COWPEAS GROWN ON THREE FLORIDA SOILS[1]

O. E. Gall and R. M. Barnette[2]

The practical use of zinc compounds for the prevention and correction of the malnutrition of a number of plants growing under a variety of soil conditions has been reported during the past decade. In Florida, Allison (1),[3] Allison, Bryan, and Hunter (2), and Allison and Hunter (3) obtained responses to zinc with corn, peanuts, and many other crops grown in the raw peat soils of the Everglades. Mowry (13) and Mowry and Camp (14) found that "bronzing" of tung trees, a malnutrition of *Aleurites fordii* and related species growing in the mineral soils of central, north, and northwest Florida, was due to a deficiency of available zinc in these soils. Also, Blackmon (7) reported the beneficial effects of zinc sulfate for the correction and prevention of "rosette" of pecans and the malnutrition of related nut species growing on mineral soils in the same area.

Barnette and Warner (4) and Barnette, *et al.* (5) reported the use of zinc sulfate for the prevention of "white bud" of corn as well as the malnutrition of velvet beans, cowpeas, millet, and other agronomic crops grown on the mineral soils of Florida. Camp (9) extended the use of zinc sulfate, mostly in the form of a zinc spray, for the correction of "frenching" of citrus trees. "Frenching" of citrus trees occurs both where there is an excess of lime in the soil and in excessively leached, acid soils. Likewise, Townsend (16) found the lack of zinc a cause for failure of beans grown on the newly cleared sawgrass soils at some distance from Lake Okeechobee in the Everglades.

In all the experiments reporting a beneficial effect of zinc, either added to the soil or used as a spray, the quantities added have been relatively small. Thus, 89% zinc sulfate was effective in preventing or correcting the malnutrition of a number of plants when applied at the rate of 5 to 20 pounds per acre in the row for agronomic crops, or ½ to 1 pound per tree (30 to 60 pounds per acre) for tree crops and even smaller quantities were sufficient when added in the form of sprays. On the other hand, the toxicity of zinc to plant growth has been abundantly proved, especially in water cultures, making it highly desirable to develop information as to the limits of toxicity of zinc under different soil conditions and for various plants. It is also of value to know methods of alleviating this toxicity.

In this connection, Freytag (11) in 1868 established that zinc replaced or rendered soluble other cations in the soil, including calcium, magnesium, potassium, and sodium. Baumann (6) attributed the great divergence of the toxic limits of zinc obtained by different work-

[1]Contribution from the Department of Chemistry and Soils, University of Florida, Agricultural Experiment Station, Gainesville, Fla. Received for publication October 13, 1939.

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[3]Figures in parenthesis refer to "Literature Cited", p. 31.

ers to the wide variations in the fixing power of soils. Thus, a much lower concentration of zinc was toxic in sandy soils than in humus and marl soils. Brenchley (8) concluded from a review of results reported by many workers that insoluble zinc compounds, such as the oxide, carbonate, phosphate, and sulfide, are seldom toxic to plant growth, while the toxic character of soluble zinc compounds at relatively low concentrations in water cultures, sand cultures, and soils with low fixing power has often been shown.

Recently, Jones, *et al.* (12) studied the reaction of zinc sulfate with the soil and concluded that there are three classes of compounds formed, namely, (a) water-soluble zinc compounds, (b) combinations of zinc with the colloidal portion of the soil (replaceable zinc), and (c) water-insoluble and non-replaceable zinc combinations, such as carbonates, phosphates, and other complex compounds. Replaceable zinc may be considered just as active as other replaceable cations in the soil and also toxic to plant growth under certain conditions. For this reason the toxic limits of replaceable zinc rather than that of water-soluble and total zinc have been studied.

EXPERIMENTAL PROCEDURE

The surface soils of a Norfolk sand, an Orangeburg fine sandy loam, and a Greenville clay loam were used for plant studies in the greenhouse. A quantity of each of these soils was air-dried in thin layers in the greenhouse, screened through a 2-mm, round-hole sieve, and thoroughly mixed.

The procedure for establishing the cultures was the same as that used by Jones, *et al.* (12). A portion of each of the screened surface soils was placed in 3-gallon coffee urn pots and treated with a concentrated zinc sulfate solution. Additional water was added to insure a contact of the zinc sulfate with all the soil. After standing in this condition for a week all salts in free solution were washed out of the soils with distilled water. Frequent tests for sulfate were made in the leachates and the washing discontinued when a negative test was obtained. Then the soils were again spread in thin layers and air-dried in the greenhouse.

The soils treated in this manner were practically saturated with replaceable zinc. The replaceable zinc contents of the three types were 1.376, 1.896, and 2.692 M.E. per 100 grams of air-dried soil[4] for the Norfolk sand, Orangeburg fine sandy loam and Greenville clay loam, respectively. Replaceable zinc was determined by the method of Cone and Cady (10) as modified by Jones, *et al.* (12).

Small glazed earthenware pots holding 1,200 grams of soil were used for the study of the toxicity of replaceable zinc. Cultures with a range of concentration of replaceable zinc were established by combining different proportions of the untreated and zinc-saturated soils. The soils were fertilized with chemically pure salts as indicated in the tables. Duplicate cultures were established for each of the soil treatments used. Corn and cowpeas were used as test plants. Ten seed of Whatley's prolific corn and of Suwannee cowpeas were planted in each of the pots. Upon germination and establishment of the seedlings, they were thinned to a uniform stand of five plants in each culture. Visually optimum moisture conditions for plant growth were maintained by frequent weighings and additions of dis-

[4]The factor for changing milliequivalents of zinc per 100 grams of soil to pounds per acre is 654, i.e., 654×M.E. of zinc per 100 grams of soil = pounds of zinc per acre.

tilled water. Each planting of corn or cowpeas was grown for approximately one month. The plants in each pot were harvested by severing the tops from the roots at the soil level. The plants were dried at 100° C. The roots were removed from the soil in the pots before another crop was planted.

EXPERIMENTAL RESULTS

Two crops of corn and two of cowpeas were grown in rotation in each of the soils used for the experiment.

The average relative weights of the corn and cowpeas were calculated on the basis of the average dry weights of plants grown in cultures without zinc treatment and fertilized with ammonium nitrate only. The results of these calculations for corn and cowpeas are given in Tables 1 and 2, respectively.

The results obtained with corn indicate that replaceable zinc is definitely toxic to plant growth at a concentration between 0.688 and 1.376 M.E. per 100 grams of air-dried Norfolk sand. The lower limit of this range of replaceable zinc was slightly toxic while the higher limit was definitely toxic. The use of 233 pounds per acre of mono-calcium phosphate did not significantly influence this range, though 1,000 pounds per acre of calcium carbonate reduced the toxicity of replaceable zinc in the culture containing 1.376 M.E. of replaceable zinc from 32% of the growth with no added replaceable zinc in the ammonium nitrate cultures to 63% in the ammonium nitrate cultures with calcium carbonate.

Lott (15) has recently shown that by lowering the hydrogen-ion concentration with additions of calcium carbonate, zinc toxicity is alleviated. It is noted that in the presence of either mono-calcium phosphate or calcium carbonate a considerable amount of replaceable zinc (0.206 M.E. or 135 pounds zinc per acre), causes a stimulation in plant growth. Unfortunately, the Norfolk sand cultures were not established so as to give a range suitable for determining more exactly the toxic limits at the higher concentrations of replaceable zinc.

The results obtained with corn at different concentrations of replaceable zinc in the Orangeburg fine sandy loam indicate that 0.758 to 1.137 M.E. of replaceable zinc per 100 grams of air-dried soil were toxic in the series of cultures with ammonium nitrate alone; the series with 1,800 pounds mono-calcium phosphate in addition showed the same range of toxicity. On the other hand, with additions of ammonium nitrate plus 4,000 pounds per acre of calcium carbonate, toxicity was shown to be within the range of 1.137 and 1.516 M.E. of replaceable zinc per 100 grams of soil. Also, with the highest concentration of 1.896 M.E. of replaceable zinc per 100 grams of air-dried soil, the 4,000 pounds per acre application of calcium carbonate decreased the toxicity to corn by an increased yield that varied from 32% without the carbonate to 61% with the carbonate. In this soil type a positive response of corn to the application of mono-calcium phosphate was noted with the lower concentrations of replaceable zinc.

The nature of these experiments precludes the determination of a definite concentration of replaceable zinc which will be toxic to the plants. For this reason a range of concentration within which the re-

TABLE I.—*The effect of increasing quantities of replaceable zinc in the soil on the growth of corn.*

Applications of fertilizing salts per acre	Relative yields of corn								
	Norfolk sand								
	0.000	0.069*	0.138	0.206	0.275	0.482	0.688	1.376	
100 lbs NH_4NO_3	100 (0.89 gram)†	95	92	89	96	93	85	32	
100 lbs. NH_4NO_3 and 233 lbs. $CaH_4(PO_4)_2$	92	98	99	113	105	95	96	34	
100 lbs. NH_4NO_3 and 1,000 lbs. $CaCO_3$	90	97	99	103	96	95	93	63	
	Orangeburg fine sandy loam								
	0.000	0.047*	0.095	0.189	0.379	0.758	1.137	1.516	1.896
150 lbs. NH_4NO_3	100 (0.87 gram)†	101	87	94	93	81	62	56	32
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	131	125	127	134	120	98	65	62	37
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	104	87	93	98	98	86	83	73	61
	Greenville clay loam								
	0.000	0.067*	0.134	0.269	0.538	1.077	1.615	2.153	2.692
150 lbs. NH_4NO_3	100 (0.91 gram)†	108	116	121	116	100	88	67	42
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	148	138	143	151	128	115	89	63	42
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	123	115	109	108	105	109	100	84	70

*M.E. of replaceable zinc per 100 grams of air-dried soil. For converting M.E. per 100 grams soil to pounds of zinc per acre multiply by 654.
†Average oven-dried weights of plants grown with ammonium nitrate without addition of replaceable zinc used as a basis for calculation of all relative yields.

TABLE 2.—*The effect of increasing quantities of replaceable zinc in the soil on the growth of cowpeas.*

Applications of fertilizing salts per acre	Relative yield of cowpeas								
	Norfolk sand								
	0.000	0.069*	0.138	0.206	0.275	0.482	0.688	1.376	
100 lbs. NH_4NO_3	100 (0.99 gram)†	96	91	86	92	71	61	25	
100 lbs. NH_4NO_3 and 233 lbs. $CaH_4(PO_4)_2$	99	96	90	82	94	74	61	35	
100 lbs. NH_4NO_3 and 1,000 lbs. $CaCO_3$	120	104	104	94	96	94	72	52	
	Orangeburg fine sandy loam								
	0.000	0.047*	0.095	0.189	0.379	0.758	1.137	1.516	1.896
150 lbs. NH_4NO_3	100 (1.5 gram)†	114	113	106	91	54	22	16	12
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	112	118	113	117	93	71	26	13	14
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	101	98	109	111	100	103	93	90	74
	Greenville clay loam								
	0.00	0.067*	0.134	0.269	0.538	1.077	1.615	2.153	2.692
150 lbs. NH_4NO_3	100 (1.27 gram)†	95	101	93	92	72	36	21	17
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	112	106	111	131	99	59	30	22	14
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	118	96	116	107	91	93	71	50	34

*M.E. of replaceable zinc per 100 grams of air-dried soil. For converting M.E. per 100 grams of soil to pounds per acre multiply by 654.

†Average oven-dried weights of plants grown with ammonium nitrate without addition of replaceable zinc used as a basis for calculation of all relative yields.

placeable zinc may begin to be toxic has been used. The higher limits of this range have been set at the concentration of replaceable zinc which will decrease the plant yields at least 25%. Logically the lower limits become the next lower concentration.

The Greenville clay loam showed that the amounts of replaceable zinc toxic to corn in the series with 150 pounds of ammonium nitrate alone were between 1.615 and 2.153 M.E. per 100 grams of air-dried soil. The same limits were observed for the series with ammonium nitrate plus mono-calcium phosphate. On the other hand, the toxic limits for the series of cultures treated with ammonium nitrate plus calcium carbonate were between 2.153 and 2.692 M.E. of replaceable zinc per 100 grams of air-dried soil. In addition to these observations, a definite increase in yields of corn plants with the application of mono-calcium phosphate to Greenville clay loam was noted with the cultures having the lower concentrations of replaceable zinc. The lower concentrations of replaceable zinc stimulated plant growth in the cultures with ammonium nitrate alone as well as in those with ammonium nitrate plus calcium carbonate.

The toxic limits of replaceable zinc for cowpeas were observed to be distinctly lower than for corn (Table 3). In the Norfolk sand cultures, the toxic limit for cowpeas was between 0.275 and 0.482 M.E. of replaceable zinc per 100 grams of soil in the ammonium nitrate and in the combination ammonium nitrate and mono-calcium phosphate treatments. On the other hand, the limits for the ammonium nitrate-calcium carbonate cultures were between 0.482 and 0.688 M.E. per 100 grams. Likewise, the carbonate increased the plant growth through the entire range of replaceable zinc concentrations.

TABLE 3.—*The toxic range of replaceable zinc for corn and cowpeas.*

Applications of fertilizing salts, per acre	M. E. of replaceable zinc per 100 grams of air-dried soil toxic to	
	Corn	Cowpeas
Norfolk Sand		
100 lbs. NH_4NO_3	0.688–1.376	0.275–0.482
100 lbs. NH_4NO_3 and 233 lbs. $CaH_4(PO_4)_2$	0.688–1.376	0.275–0.482
100 lbs. NH_4NO_3 and 1,000 lbs. $CaCO_3$	0.688–1.376	0.482–0.688
Orangeburg Fine Sandy Loam		
150 lbs. NH_4NO_3	0.758–1.137	0.379–0.758
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	0.758–1.137	0.379–0.758
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	1.137–1.516	1.516–1.896
Greenville Clay Loam		
150 lbs. NH_4NO_3	1.615–2.153	0.538–1.077
150 lbs. NH_4NO_3 and 1,800 lbs. $CaH_4(PO_4)_2$	1.615–2.153	0.538–1.077
150 lbs. NH_4NO_3 and 4,000 lbs. $CaCO_3$	2.153–2.692	1.077–1.615

The toxic limit of replaceable zinc for cowpeas in the Orangeburg fine sandy loam was between 0.379 and 0.758 M.E. for the cultures receiving ammonium nitrate alone as well as those receiving both

ammonium nitrate and mono-calcium phosphate. However, the addition of phosphate stimulated the growth of the cowpeas in the lower zinc applications. The toxic limit of concentration was increased to between 1.516 and 1.896 M.E. of replaceable zinc per 100 grams by an application of 4,000 pounds per acre of calcium carbonate. The toxicity in the cultures with 1.896 M.E. of replaceable zinc per 100 grams of air-dried soil was very materially reduced by the calcium carbonate.

With the Greenville clay loam a concentration somewhere between 0.538 and 1.077 M.E. of replaceable zinc per 100 grams of soil proved toxic to cowpeas in the cultures with ammonium nitrate and mono-calcium phosphate, while the range for the cultures receiving calcium carbonate was between 1.077 and 1.615 M.E. Both treatments receiving mono-calcium phosphate and calcium carbonate, respectively, showed stimulated growth with the lower concentrations of replaceable zinc.

The toxic limits of replaceable zinc for corn and cowpeas grown in a Norfolk sand, an Orangeburg fine sandy loam, and a Greenville clay loam with ammonium nitrate, ammonium nitrate plus mono-calcium phosphate, and ammonium nitrate and calcium carbonate are summarized in Table 3. The results indicate that in the Norfolk soil the point of toxic limit to plants falls nearer the lower than the upper limits of the ranges used.

The quantities of replaceable zinc necessary to be toxic to corn increased with an increase in the total replaceable zinc content of the soils. In other words, the toxic limits were raised with an increase in the quantity of replaceable zinc held in the soil, being at a lower range in Norfolk sand and increasing in the Orangeburg fine sandy loam and Greenville clay loam. Mono-calcium phosphate did not change these ranges. Calcium carbonate, however, materially increased the quantity of replaceable zinc necessary to be toxic to corn.

The germination of corn was not decreased by replaceable zinc but growth was slow above toxic concentrations. At these concentrations, the leaves turned yellow between the veins, while the veins themselves remained intensely green. The rate of growth in these cultures was greatly reduced and the plants remained small in comparison with the other cultures where zinc was not present in toxic concentrations.

In the absence of calcium carbonate the toxic concentrations of zinc were very much lower for cowpeas than for corn. Under these conditions of treatment the point of toxic concentration for the Norfolk sand fell somewhere in the concentration range of 0.275 to 0.482 M.E. of replaceable zinc per 100 grams of air-dried soil, that for the Orangeburg fine sandy loam between 0.379 and 0.758 M.E., and that for Greenville clay loam between 0.538 and 1.077 M.E., respectively. It is thus seen that definitely larger quantities of replaceable zinc were required to produce toxic effects on cowpeas in the heavier soils than on the lighter types. Calcium carbonate increased the amount of replaceable zinc necessary to cause toxicity in all three types. This shows the effect of calcium carbonate in overcoming, or at least alleviating, the toxic properties of large quantities of replaceable zinc.

Cowpea seedlings were severely stunted by toxic concentrations of replaceable zinc. Examination of the roots at the toxic concentrations of the three soils showed that nodulation had been decreased at the lower limits of toxicity and prohibited at the higher limits. The germination was not affected by the toxic concentrations of replaceable zinc but growth was slow with the formation of only two to four leaves. These stunted plants remained green until the edges of the leaves began to curl and die. Just before harvest, part of the dead leaves dropped from the stunted plants, but the plants remained alive until harvest.

A series of such cultures grown in the Orangeburg fine sandy loam with various quantities of replaceable zinc, with and without calcium carbonate, are shown in Fig. 1. The beneficial effects of calcium carbonate in preventing the extreme toxicity may be noted.

SUMMARY

Soluble zinc compounds are used under a variety of conditions in Florida to prevent or correct malnutrition of a number of plants caused by a deficiency of available zinc. The zinc accumulates in the

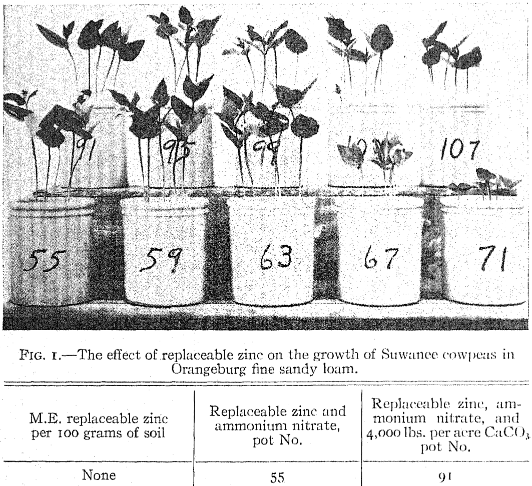

FIG. 1.—The effect of replaceable zinc on the growth of Suwanee cowpeas in Orangeburg fine sandy loam.

M.E. replaceable zinc per 100 grams of soil	Replaceable zinc and ammonium nitrate, pot No.	Replaceable zinc, ammonium nitrate, and 4,000 lbs. per acre $CaCO_3$ pot No.
None	55	91
0.095	59	95
0.379	63	99
1.137	67	103
1.896	71	107

soil either in the mobile replaceable form or in definite water-insoluble forms. The former is known to be toxic to plant growth when it accumulates in sufficient quantities; the latter are seldom toxic to plant growth. In order to establish the toxic limits of zinc for certain plants and to determine methods of preventing or alleviating this toxicity, three series of greenhouse cultures were employed.

A simple but expedient method is described for preparing greenhouse cultures for the above purpose with a Norfolk sand, an Orangeburg fine sandy loam, and a Greenville clay loam, giving ranges of replaceable zinc in the soils. The principal feature of the technic is the use of soils which had been previously saturated with replaceable zinc and washed free from soluble salts, combined in varying proportions with the corresponding air-dried untreated soils to give a suitable range in concentration of replaceable zinc in each soil.

Two crops of corn and cowpeas as test plants were grown for four weeks each in rotation. The weight of the dry plants from each culture was obtained. The results of the tests may be summarized as follows:

1. Replaceable zinc became toxic to corn on a Norfolk sand between the concentrations of 0.688 and 1.376 M.E. per 100 grams (451–902 pounds Zn per acre); between 0.758 and 1.137 M.E. (497–734 pounds Zn per acre) on an Orangeburg fine sandy loam; and between 1.615 and 2.153 M.E. (1,051–1,402 pounds Zn per acre) on a Greenville clay loam.

2. Replaceable zinc became toxic to cowpeas between the concentrations of 0.275 and 0.482 M.E. per 100 grams (181–316 pounds Zn per acre) on a Norfolk sand; between 0.379 and 0.758 M.E. (246–479 pounds Zn per acre) on an Orangeburg fine sandy loam; and between 0.538 and 1.077 M.E. (351–701 pounds per acre) on a Greenville clay loam.

3. The application of mono-calcium phosphate at the rate of 233 pounds per acre to the Norfolk sand and 1,800 pounds per acre to the Orangeburg fine sandy loam and the Greenville clay loam did not change the toxic limits of the replaceable zinc for corn or cowpeas. The presence of phosphate as a plant nutrient, however, stimulated the growth of corn and cowpeas on the Orangeburg fine sandy loam and the Greenville clay loam, while no effect was noted on the Norfolk sand.

4. The use of calcium carbonate at the rate of 1,000 pounds per acre on the Norfolk sand and 4,000 pounds per acre on the Orangeburg fine sandy loam and the Greenville clay loam definitely increased the concentrations at which replaceable zinc became injurious to corn and cowpeas and greatly alleviated the toxic condition.

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THE GERMINATION OF SEED OF *ORYZOPSIS HYMENOIDES*[1]

Vivian K. Toole[2]

BECAUSE of the difficulty encountered in obtaining satisfactory field stands and laboratory germination of seed of *Oryzopsis hymenoides* (Roem. & Schult.) Ricker, Indian ricegrass, M. M. Hoover of the Soil Conservation Service suggested the study of the germination requirements of this seed.

Huntamer (1)[3] has presented results on the different strains of *Oryzopsis hymenoides,* the nature of the resistance of the seed to germination, and of various treatments to overcome this resistance. She gives a rather complete review of the literature on the distribution of this plant and its value as a forage grass. Stoddart and Wilkinson (2) have published on the treatment of the seed with concentrated sulfuric acid.

METHODS

The seed was furnished by various Soil Conservation agencies through the courtesy of M. M. Hoover. The seed as received was cleaned by means of an air blast blower. The "seed" referred to in this paper is the fruit with the attached lemma and palea. The blown seed was placed in water for 5 minutes to make a more complete separation of the heavy and light seed. Stoddart and Wilkinson (2) concluded that only those seeds which sank in water within 5 minutes had a reasonable chance to grow.

The seed was germinated in duplicate tests of 100 seeds each on various media in Petri dishes. Paper toweling in the Petri dishes was a satisfactory substratum for the treated seeds which germinated quickly. After an extended period in the germinator, the toweling tended to lose its water-absorbing capacity. For this reason, a sandy soil or a mixture of peat and sand in Petri dishes was more satisfactory for non-treated seed that required a long period for germination.

The seed was considered as germinated when it had produced a normally developed root and plumule. The sprouts grew more slowly at the low temperatures, developing into a "stubby" but otherwise normal sprout. In many of the tests of the non-treated seed and of the seed pretreated with approximately 71% sulfuric acid for 30 minutes, the root lacked the vigor to push itself from within the lemma and palea and so grew coiled around the caryopsis. The two types of sprouts just described were counted as germinated. The most common abnormality, both in the treated and non-treated seed, was the lack of root development. Seeds showing this abnormality were not recorded as germinated.

The seed was germinated over a wide range of constant and alternating temperatures. The alternation of temperature was obtained by transferring the test from one chamber to another, the test remaining at the first temperature listed for 17 and at the second temperature for 7 hours daily. The temperature of the germi-

[1]Contribution from the Division of Fruit and Vegetable Crops and Diseases, U. S. Dept. of Agriculture, Washington, D. C. Received for publication October 28, 1939.

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[3]Figures in parenthesis refer to "Literature Cited", p. 41.

nation chambers was controlled within 1 degree of that listed. In order to obtain light exposure accompanying a high temperature alternation, the test was placed in a north window of an air conditioned building for the 17-hour period. The room temperature varied from 16° to 24° C.

To prechill the seed, it was placed in Petri dishes on top of moistened peat and sand or soil and held at 3° C for various lengths of time. The temperature of the 3° chamber varied between 2° and 5°. The time of counting is computed from the day the seed was placed to prechill.

To treat the seed with sulfuric acid, the seed was placed in a small porcelain crucible, covered with an excess of acid, and stirred constantly for the designated time, then washed in running tap water for 30 to 45 minutes and dried thoroughly before placing to germinate. The approximately 71% sulfuric acid used was made by diluting 3 parts of concentrated sulfuric acid (sp. gr. 1.84) with 1 part distilled water by volume.

Germination figures summarized in Tables 1, 2, and 3 are in all cases mean values, based on duplicate tests of 100 seeds each. In Table 2, half percents have been raised to the next higher percentage. Values for error and tests of significance of difference have been calculated by the analysis of variance method as adapted by Snedecor (3).

PRESENTATION OF RESULTS

TEMPERATURE

In preliminary tests, the effect of constant temperatures of 3°, 10°, 15°, 20°, 25°, 30°, and 35° C, temperatures alternations of 10° to 25°, 15° to 25°, 10° to 30°, 20° to 30° (with light), 15° to 35°, 20° to 35°, 20° to 40°, 25° to 15°, 35° to 10°, room to 10°, room to 25°, and room to 35°, and of prechilling at 3° for various periods was determined on untreated blown seed of *O. hymenoides*. The constant temperature of 3° or prechilling at 3° for 28 days or longer before placing at a higher temperature proved to be the best for germination. Germination was very slow at this low temperature, requiring 100 or more days. The germination of the different samples varied from 2 to 62%. The other temperatures gave exceedingly low results. The above results are in accordance with the conclusions presented by Huntamer (1) regarding embryo dormancy.

STORAGE TEMPERATURE AND GERMINATION TEMPERATURE

The blown seed of three samples of 1937 seed was stored in sealed containers at three different controlled temperatures and in paper bags in an air-conditioned room on January 12, 1938. Sample No. 766900 was received from Kansas and sample No. 766908 from New Mexico as 1937 seed, sample No. 766906 was collected near Greenhorn, Colorado, in June 1937, and all three samples were received in the laboratory in December 1937. At the time the seed was put in storage the moisture content was approximately 7%.

On July 1, 1938, the seed was placed to germinate at the seven different temperatures shown in Table 1. The difference between sample No. 766908 and samples Nos. 766900 and 766906 is of high significance. Sample No. 766908 appeared to be of low viability, germinating very poorly at all temperatures regardless of storage conditions and with few sound seed remaining at the end of the test.

TABLE 1.—*Germination in 125 days of seed of Oryzopsis hymenoides previously held in storage at four different temperatures, means of duplicate 100 seed tests.**

Sample No.	Temperature of storage chamber, °C	Percentage germination response at indicated temperatures								Mean.	
		Number of Observations	3° C	15° C	20° C	15–25° C	20–30° C	20–35° C	20–40° C	Number of Observations	Germination, %
766900	Room	2	31.0	33.5	30.0	34.5	35.0	28.0	19.0	14	30.14
	30°	2	30.5	46.0	29.5	48.0	49.5	29.0	22.0	14	36.35
	20°	2	30.5	27.5	5.5	14.5	12.0	5.0	12.5	14	15.35
	2°	2	21.0	27.5	4.5	5.0	3.5	2.5	3.0	14	9.57
	Mean for sample	8	28.25	33.62	17.37	25.5	25.0	16.12	14.12	56	22.85
766906	Room	2	41.0	29.0	25.5	23.0	20.0	17.5	17.5	14	24.78
	30°	2	51.0	49.0	33.0	47.0	44.0	40.5	29.5	14	42.0
	20°	2	24.5	13.0	5.5	12.0	11.0	5.5	6.5	14	11.14
	2°	2	14.5	7.5	5.5	5.5	6.5	4.5	0.5	14	6.35
	Mean for sample	8	32.75	24.62	17.37	21.87	20.37	17.0	13.5	56	21.06
766908	Room	2	4.0	10.0	9.5	5.0	6.5	8.0	6.0	14	7.0
	30°	2	8.5	10.5	8.5	5.0	11.5	5.5	9.0	14	8.35
	20°	2	3.5	1.5	2.0	2.5	5.0	0.5	3.0	14	2.57
	2°	2	3.5	0.5	3.5	4.5	2.5	3.5	4.0	14	3.14
	Mean for sample	8	4.87	5.62	5.87	4.25	6.37	4.37	5.5	56	5.24
Mean for room...........		6	25.33	24.16	21.66	20.83	20.5	17.83	14.16	42	20.64
Mean for 30°............		6	30.00	35.16	23.66	33.33	35.0	25.0	20.16	42	28.90
Mean for 20°............		6	19.50	14.00	4.33	9.66	9.33	3.66	7.33	42	9.68
Mean for 2°.............		6	13.0	11.8	4.5	5.0	4.16	3.5	2.5	42	6.35
Mean for all storage temperatures............		24	21.95	21.28	13.53	17.20	17.24	12.49	11.04	168	16.39

*Minimum differences required for significance are: Between means of 2 observations, 15.61%; 6 observations, 4.68%; 8 observations, 3.88%; 14 observations, 2.82%; 24 observations, 2.10%; 42 observations, 1.58%; 56 observations, 1.35%.

LIBRARY

The difference between 30° C and room storage is significant for sample No. 766900, and of high significance for sample No. 766906, showing 30° storage as superior. Seed stored at 30° germinated best and about the same at 3°, 15°, 15° to 25°, and 20° to 30°, but even at these temperatures there were many sound seeds remaining at the end of the test. The seed stored at 20° and at 2° was more dormant. The difference in the germination of the seed stored at these two temperatures and that stored at the higher temperatures is significant, and in most cases highly significant, especially at the higher germination temperatures.

Most of the germination at 3° C occurred between 63 and 125 days and between 10 and 35 days at the higher germination temperatures.

MECHANICAL SCARIFICATION

Scarification of the seed with emery paper or by rotating in a metal box with small gravel at a high speed for 5, 10, 15, 20, 30, and 40 minutes produced injury to the exserted embryo. Huntamer (1) found mechanical scarification with sand paper injurious to the embryo and endosperm. She obtained better results by removing the glumes from individual seeds with a needle.

TREATMENT WITH SULFURIC ACID

Preliminary treatments with concentrated sulfuric acid for 3, 5, 10, 15, and 20 minutes resulted in injury to the seed. Very low germination results were obtained.

A general survey of treated and non-treated seed.—The heavy seed of eight samples separated in water was treated with approximately 71% sulfuric acid for 0, 30, 45, 60, and 120 minutes and germinated at 20° to 30° C with light and 3°. The results are given in Table 2.

In all cases the optimum acid treatment for a particular sample gave higher results than the test on untreated seed. In general 45 to 60 minutes treatment with acid appeared to be the best. However, there was an indication that samples with large dark seed (samples Nos. 760104 and 769271) required a longer acid treatment. Even after the most favorable acid treatment some samples had apparently sound seed remaining at the end of the test. This was most pronounced with the two samples with large dark seed, which were of the type described by Huntamer (1) as being extremely difficult to germinate. Sample No. 757542 which germinated 90% after treatment was probably the type designated as small dark seed by the other writers. The heavy seed in this study, with the exception of the three samples mentioned above, were of medium size and of a black to brown color.

There does not appear to be any consistent difference between germination temperatures for treated seed; for some samples 20° to 30° C is better and for other samples 3° is better.

Heavy and light seed.—The blown seed of samples Nos. 766900, 766906, and 766908 was placed in water for 5 minutes to determine the percentage of heavy and light seed. The heavy and light seed were then treated separately with approximately 71% sulfuric acid for 0, 30, 45, 60, 90, and 120 minutes, respectively, and then germi-

nated at 20° to 30° C with light and at 3°. The results of the germination test on the heavy seed is given in Table 3 and the analysis of variance in Table 4.

TABLE 2.—*Germination of eight samples of seed of Oryzopsis hymenoides after various treatments with approximately 71% sulfuric acid.*

Sample No.	Place of collection	Date collected	Percentage germination in 84 days after treatment with approximately 71% H_2SO_4 for indicated minutes					
			0	30	45	60	90	120
			Germination Temperature 20° to 30° C					
757442	Arizona	July 14, '36	0	—	—	85*	—	—
760104	Arizona	————	6	16	28	43	47*	41
757542	Wyoming	————	34	—	90*	90†	43	—
751463	New Mexico	July 22, '36	2	—	—	66	77‡	—
769271	New Mexico	June 19, '38	1	0	1	3	36§	—
766908	New Mexico	1937	7	6	13	22*	7	1
766900	Kansas	1937	30	70	80	83‡	81	23
766906	Colorado	June 1937	31	73	79	69	29	1
			Germination Temperature 3° C					
757442	Arizona	July 14, '36	24	—	—	88*	—	—
760104	Arizona	————	6	18	16	25	38	27
757542	Wyoming	————	60	—	67	74	23	—
751463	New Mexico	July 22, '36	30	—	—	57	56	—
769271	New Mexico	June 19, '38	0	0	0	3	16	—
766908	New Mexico	1937	4	11	15	22*	10	0
766900	Kansas	1937	76	78	87	89*	90*	22
766906	Colorado	June 1937	53	75	78	81*	45	1

*Few sound seed remaining. †No sound seed remaining.
‡Several sound seed remaining. §Many sound seed remaining.

The differences among the samples for the heavy seed are of high significance. At the germination temperatures of 20° to 30° C with light, the 45- and 60-minute treatments are significantly better than 30 minutes and the differences when compared with the other treatments are highly significant. At the germination temperature of 3°, the 60-minute treatment is significantly better than the 30-minute treatment, with the 45-minute treatment falling midway between. The other treatments are significantly lower than the 30-minute treatment at this temperature. The mean of all samples at the two germination temperatures shows no difference between the 45- and 60-minute treatments and these two are far superior to the other treatments. The mean of all samples germinated at 3° is of high significance in comparison with the mean of all samples germinated at 20° to 30°, but this significance is due to the differences at the unfavorable treatments since the 30-, 45-, and 60-minute treatments do now show this significant difference. The 90- and 120-minute treatments, except the 90-minute treatment on sample No. 766900, produced injury causing fungus infection. As shown by Huntamer (1), the indurated lemma and palea prevented the germination of untreated samples. Although pre-treatment with acid hastens the germination

at 3°, it is still comparatively slow, germinating mostly between 21 and 49 days, while the germination of the treated seed at 20° to 30° is practically complete in 21 days.

TABLE 3.—*Germination in 84 days of heavy seed of Oryzopsis hymenoides at indicated temperatures and specified treatment, means of duplicate 100 seed tests.**

Sample No.	No. of observations	Percentage germination response after treatment with approximately 71% H_2SO_4 for indicated times: 0 minutes	30 minutes	45 minutes	60 minutes	90 minutes	120 minutes	Mean: No. of observations	Germination %
				Germination Temperature 20° to 30° C with Light					
766900	2	30.0	70.0	79.5	82.5	80.5	22.5	12	60.83
766906	2	30.5	73.0	78.5	68.5	28.5	1.0	12	46.66
766908	2	7.0	5.5	12.5	22.0	7.0	0.5	12	9.08
Mean	6	22.5	49.5	56.83	57.66	38.66	4.0	36	38.86
				Germination Temperature 3° C					
766900	2	75.5	77.5	86.5	88.5	89.5	21.5	12	73.16
766906	2	52.5	75.0	77.5	81.0	44.5	0.5	12	55.16
766908	2	4.0	10.5	15.0	21.5	10.0	0.0	12	10.16
Mean	6	44.0	54.33	59.66	63.66	48.0	3.66	36	46.13
				Means					
	12	33.25	51.91	58.24	60.66	43.33	3.83	72	42.49

*Minimum differences required for significance are: Between means of 2 observations, 18.45%; 6 observations, 5.53%; 12 observations, 3.63%; 36 observations, 2.01%.

TABLE 4.—*Analysis of variance of germination data given in Table 3.*

Source of variation	Degree of freedom	Mean square
Total	71	—
Temperature	1	960.88
Treatments	5	4,719.31
Sample	2	21,022.26
Temperature × treatment	5	178.18
Temperature × sample	2	196.27
Treatment × sample	10	886.86
Treatment × temperature × sample	10	100.06
Remainder (error)	36	18.43

A separate analysis of the germination results with various treatments of the heavy and light seed shows that there was no significant difference in response of the heavy and light seed to the duration of acid treatments. The light seed was of low viability.

DISCUSSION

The seed of *Oryzopsis hymenoides* is resistant to germination. Huntamer (1) found two types of dormancy in the seed, *viz.*, mechanical

and embryo dormancy. The first could be remedied by removing the coat restriction and the second by moist, low temperature stratification or by long periods of dry storage. The present work gives some evidence of the two types of dormancy, but not a sharp distinction between them. Most samples germinated after the removal of the coat restriction by acid. Huntamer (1) showed that indurated lemma and palea and the grain coats were not impermeable to water. She found total exclusion of oxygen prevented germination. She demonstrated that pricking the swollen grain over the embryo had a stimulating effect on some grains, being more effective on non-dormant than dormant embryos.

In contrast to the results of other investigators, the present work showed concentrated sulfuric acid to be injurious. However, suitable treatment with approximately 71% sulfuric acid was found to be effective. Some samples did not give complete germination even then, indicating embryo dormancy. Although a complete age series was not available for observation, embryo dormancy appeared more related to seed type than to the age of the seed. The temperature at which the seed is stored affects the degree of dormancy. Seed with 7% moisture stored in sealed containers at 30° C was less dormant than similar seed stored at 20° or 2°. Huntamer (1) observed that seeds from plants grown under low moisture and high temperature conditions were more dormant than those from plants grown under moderate rainfall and temperature conditions.

Huntamer (1) distinguished types or races that responded differently to conditions of germination and to acid treatment. There is some evidence of similar differences in the seed used in this study. Large dark seed appeared not only to possess a more protracted embryo dormancy than the small or medium sized brown to black seed but to require a longer acid treatment. Huntamer states that concentrated sulfuric acid scarification of large dark "seeds" gave negative results. The highest results obtained by the writer on this type of seed was 35 and 45% after pre-treatment with acid. Huntamer found that small, light-colored seeds required 10 minutes and the small, dark seeds 15 minutes treatment with concentrated sulfuric acid when treated at 19° C. When treated at 25°, 12.5 to 17.5 minutes and 15 to 20 minutes, respectively ,were required for the two classes of seed. Treatment with 25 and 50% acid did not remove the mechanical restraint of the glumes. Stoddart and Wilkinson (2) found 15 to 45 minutes for very small seed and 60 to 120 minutes for very large seed to be the optimum treatment with concentrated sulfuric acid. These acid treatments were apparently made at room temperature. The writer found 45 to 60 minutes treatment with approximately 71% sulfuric acid at room temperature to be the optimum treatment for small or medium sized brown to black seed with a possible indication of 90 minutes as better for large dark seed.

There appeared to be no difference in the length of treatment required for the heavy and light weight seed as separated by placing in water for 5 minutes. The low results with the light seed agree with those of Stoddart and Wilkinson (2) who found it to be of little value, detracting from the value of the bulk of seed.

For untreated seed the germination temperature of 3° C or 15° is best. However, the germination was very slow and not complete at these temperatures. For acid-treated seed 3° or 20° to 30° is equally good, but the germination is quicker at the higher temperature. Huntamer (1) gives 20° as the optimum germination temperature.

Tests were made on the effect of using a dilute solution of potassium nitrate to moisten the substratum. The results with potassium nitrate agree with those of Huntamer (1) who found the seed to be non-sensitive.

Although at some of the germination temperatures, the seed was exposed to daylight, no definite check was made in complete darkness; however, Huntamer (1) stated that there was no benefit of the exposure of the seed to light.

SUMMARY

1. A study was made of various treatments to overcome the resistance to germination of seed of *Oryzopsis hymenoides*.

2. A medium of sandy soil or of a mixture of sandy soil with peat was good for extended tests because it provided a uniform moisture supply over the entire period. Moistened paper toweling appeared to be as good for treated seed which germinated more promptly.

3. Fresh untreated seed germinated best at 3°, or by prechilling at 3° for at least 28 days before placing at a higher temperature.

4. Seed stored at high temperatures (room and 30°) was less dormant than seed stored at lower temperatures (20° or 2°).

5. Untreated seed held in storage at high temperatures germinated at higher temperatures than that held in storage at low temperatures. However, a low germination temperature of 3° or 15° appeared to be the optimum regardless of previous storage.

6. Fresh untreated seed required over a hundred days for germination at a low temperature.

7. Maximum germination of untreated seed held in storage occurred between 63 and 125 days when germinated at 3°; between 10 and 35 days when germinated at higher temperatures.

8. The seed of *O. hymenoides* was not sensitive to potassium nitrate.

9. Mechanical scarification produced injury to the exserted embryo.

10. Treatment of the seed with concentrated sulfuric acid resulted in injury.

11. The mechanical resistance of the indurated lemma and palea could be overcome by treatment with approximately 71% sulfuric acid for 45 or 60 minutes. Large dark seeds probably required longer treatment.

12. Some samples of seed of *O. hymenoides* appeared to have a dormant embryo since the seeds did not germinate after the mechanical resistance of the lemma and palea had been removed.

13. Seed receiving the optimum acid treatment germinated equally well at 3° or 20° to 30°.

14. After the optimum acid treatment, the germination of apparently viable seed of most samples was complete in 21 days at 20° to 30°, and in 70 days at 3°.

15. By placing heavy "blow" seed in water for 5 minutes, the lighter seed floated off. This seed was of doubtful value.

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THE EFFECT OF THE VETCH CROPPING HISTORY AND CHEMICAL PROPERTIES OF THE SOIL ON THE LONGEVITY OF VETCH NODULE BACTERIA, *RHIZOBIUM LEGUMINOSARUM*[1]

W. B. ANDREWS[2]

THE longevity of soybean nodule bacteria (*Rhizobium joponicum*) in relation to the length of time since soybeans had been grown was studied by Wilson (3).[3] He found that "there seemed to be no relationship between the frequency of the occurrence of the plant symbiont on the soil and the number of Rhizobium joponicum in the soil. There is no evidence that the reaction or the moisture content of the samples, or the influence of the crop on the soil when the samples were collected, exerted a dominating influence on the number of Rhizobium joponicum that were found in the soil samples."

Hawkins (2) found that the growth of vetch for one year on sandy soil did not supply sufficient nodule bacteria for vetch on the following year.

In 1897 Duggar (1) found that dipping vetch seed into muddy water made from soil which had grown wild vetch for several years increased the yield from 232 to 2,540 pounds of cured vetch hay per acre. He tested four soils which had not previously grown cultivated vetch or related crops. The increase in yield due to inoculation was 38, 38, 186, and 466% of the yield without inoculation for the four soils.

The purpose of the work reported in this paper was to determine the need of vetch for additional inoculation after growing vetch for one or more years on a soil and to determine the relation of chemical properties of the soil to the longevity of the nodule bacteria (*Rhizobium leguminosarum*), and the relation of one chemical property to another.

PROCEDURE

Composite samples of soil were obtained from fields with known vetch history. The surface inch of soil was removed before taking the soil to be used. A quart fruit jar full of soil was obtained from each field. A top without the rubber was put on the jar, which permitted the exchange of gases without a serious change in moisture content.

The presence of the vetch nodule bacteria was determined by inoculating vetch seed for 30 feet of row with a fruit jar top full of soil which is approximately 60 grams. The yield data are averages of four to six replications.

Available phosphorus was determined by the Truog method; soluble iron was determined by the Comber method combined with a photolometer for taking the reading; and pH was determined by the use of a glass electrode. The data are reported in Table 1.

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[1]Contribution from the Agronomy Department, Mississippi Agricultural Experiment Station, State College, Miss. Approved by the Director as Paper No. 21, new series. Received for publication November 8, 1939.

[2]Associate Agronomist.

[3]Figures in parenthesis refer to "Literature Cited", p. 47.

TABLE 1.—*Longevity of vetch nodule bacteria.*

Soil No.	Vetch history*	pH	Yield in lbs. per acre green weight	Available phosphorus, p.p.m.	Soluble iron, p.p.m.
101	0–3$_1$	4.2	3,117	12	41
103	0–5$_1$	4.2	2,556	28	89
102	0–5$_1$	4.3	2,013	40	36
119	0–3?	4.4	2,517	14	3
104	0–6$_1$	4.6	2,488	75	8
19	0–2$_2$	4.7	4,201	126	15
122	0–2$_2$	4.7	2,517	16	2
126	0–?	4.7	2,314	17	4
134	0–1$_1$	4.7	2,822	40	7
11	No.–V.	4.8	1,491	102	11
108	0–3$_1$	4.8	5,169	20	5
120	0–4$_1$	4.8	3,838	31	5
106	0–8$_1$	4.8	4,951	43	8
117	0–3$_1$	4.8	4,492	14	4
136	0–2$_3$	4.8	2,101	203	92
54	0–3$_1$	4.8	4,598	16	13
110	0–2$_1$	4.8	3,799	15	3
113	0–2?	4.8	2,023	24	6
51	0–5$_1$	4.9	1,249	29	23
118	0–3$_3$	4.9	3,485	15	4
29	?–1	4.9	1,767	28	29
116	1–1$_2$	4.9	2,556	13	5
25	0–1?	5.0	3,461	32	6
133	0–1$_3$	5.0	1,186	18	5
112	No.–V.	5.0	3,862	12	3
114	1–2$_1$	5.0	1,767	12	9
52	0–3$_1$	5.0	3,746	30	14
131	0–3$_1$	5.1	3,499	99	5
36	3–4$_1$	5.1	3,291	25	21
37	3–4$_1$	5.1	2,967	33	13
28	1–1$_3$	5.1	5,121	32	23
18	0–1$_1$	5.1	4,162	143	9
26	0–1?	5.2	4,274	43	4
115	1–1$_3$	5.2	3,165	19	2
49	No.–V.	5.2	1,815	144	20
109	0–2$_1$	5.2	4,143	12	2
107	0–2$_1$	5.3	3,606	9	2
105	0–6$_1$	5.3	5,025	106	7
21	0–1$_1$	5.3	2,856	130	13
203	0–5$_3$	5.3	2,004	9	2
31	0–1?	5.3	6,776	26	5
38	3–S?	5.3	1,588	44	28
20	0–2?	5.4	4,274	27	6
7	No.–V.	5.4	1,467	129	12
12	9–1?	5.4	3,025	140	15
34	3–S?	5.4	2,120	47	14
27	1–1?	5.4	5,653	45	5
48	0–1$_3$	5.4	5,682	51	13
127	0–3$_1$	5.5	2,294	5	1
22	0–2$_1$	5.5	4,937	30	15
23	0–1$_1$	5.5	5,750	124	15
125	0–S$_2$	5.5	3,194	14	2
135	0–1$_1$	5.5	3,640	28	2

*Vetch history: First figure indicates number of years since vetch; second figure, years of vetch; S = several but the exact number is unknown. 1, 2, 3, 4 farmers' opinion of success of vetch. 1 good; 2 fair; 3 poor; 4 failure; ? unknown.

TABLE 1.—*Concludued.*

Soil No.	Vetch history*	pH	Yield in lbs. per acre green weight	Available phosphorus, p.p.m.	Soluble iron p.p.m.
128	2–1_1	5.5	3,882	24	5
33	3–S?	5.5	4,714	48	15
202	0–1_1	5.6	4,240	19	3
35	3–3?	5.6	2,042	43	12
111	0–1_1	5.6	3,901	9	3
30	0–3_1	5.6	6,156	36	30
132	0–1_1	5.6	3,494	11	2
9	0–8_1	5.6	5,692	200	7
43	No.–V.	5.6	1,955	90	9
53	No.–V.	5.6	4,821	35	10
1	No.–V.	5.7	3,378	195	11
6	1–6_1	5.7	4,671	34	6
121	0–1_2	5.7	3,596	23	2
130	0–S_1	5.7	3,010	10	2
13	3–10_1	5.8	5,460	193	11
2	No.–V.	5.8	3,741	170	9
10	No.–V.	5.8	4,104	161	7
4	0–2_1	5.8	5,881	102	6
46	0–1?	5.8	5,895	51	16
50	No.–V.	5.9	944	36	1
40	No.–V.	5.9	1,515	27	11
15	5–S?	6.0	6,791	6	3
24	0–1?	6.0	5,687	34	7
45	2–1?	6.0	5,624	152	6
47	0–1?	6.0	6,379	19	12
17	5–S_1	6.0	5,363	213	0
14	5–S_2	6.0	6,074	186	3
201	0–2_2	6.1	2,914	13	2
32	4–S?	6.2	3,853	21	7
41	No.–V.	6.3	1,888	112	3
8	No.–V.	6.4	2,168	197	0
5	No.–V.	6.4	4,613	143	3
16	5–S_1	7.1	5,261	60	2
42	No.–V.	7.1	3,451	248	2
124	Wild $V._1$	7.2	6,011	29	1
44	1–1_1	7.8	4,724	133	3
Commercial inoculation..........			4,598		
No inoculation..................			1,176		

RESULTS AND DISCUSSION

RELATION OF SOIL REACTION TO AVAILABLE PHOSPHORUS

Various workers have shown that soil treatments in the field which reduce the acidity of the soil increase the available phosphorus. In the data reported, the soils were taken at random over the counties involved without reference to previous fertilizer treatment. The data show that there is a tendency for the soils which approach a neutral reaction to have a higher available phosphorus content than extremely acid soils, but that the tendency is only slight. There were many extremely acid soils with a high to very high available phosphorus content. Also certain of the soils with a high reaction were low in phosphorus.

RELATION OF SOLUBLE IRON TO SOIL REACTION

At a pH of 6.0 and above the soluble iron varied from a trace to 12 p.p.m. The number of soils in this range was only 15. Soils 101, 102, and 103 are soils very high in organic matter and they were also very high in soluble iron. The soluble iron in the soils with a pH of 4.4 to 5.9 varied from 2 to 92 p.p.m. and there was no indication that the soluble iron was associated with the reaction over this range.

There was no relation between soluble iron and available phosphorus.

LONGEVITY OF VETCH NODULE BACTERIA
(*Rhizobium leguminosarum*)

The soils obtained were used to inoculate vetch seed. One fruit jar top full of soil was used to inoculate seed for 30 feet of row. The seed were planted on soil which had not previously grown vetch.

The yield of vetch without inoculation was 1,176 pounds of green vetch per acre. The yield of vetch inoculated with commercial inoculation was 4,598 pounds of green vetch per acre.

There were 15 soils which had not previously grown vetch or related cultivated plants. When three of these soils were used to inoculate vetch, the yields were over 4,000 pounds of green vetch per acre. When five of them were used, the yields were between 3,000 and 4,000 pounds of green vetch per acre. Four soils produced yields which were close to the yields of the check. The other three soils produced increases in yield over the check which indicate the presence of the nodule bacteria. From these data it appears that eight of the soils had sufficient bacteria for vetch even though no vetch or related cultivated plants had been grown previously and that three more of them may have had enough bacteria for vetch planted on the field from which the soil came.

Thirty-four out of the 77 soils which had previously grown vetch produced over 4,000 pounds of vetch, 12 of them produced over 1,000 pounds more vetch than the commercial inoculation. Apparently 12 soils had nodule bacteria which were superior to the commercial culture and 34 had nodule bacteria in one fruit jar top full of soil per 30 feet of row which were just as good. Nineteen of the soil produced 3,000 to 4,000 pounds of vetch per acre, and only two soils produced no measurable increase in yield, while only three soils made low increases in yield. Seventy-two out of the 77 soils used to inoculate vetch increased the yield over 800 pounds, 53 increased it over 1,800 pounds, 34 increased it over 2,800 pounds. The commercial culture increased the yield 3,422 pounds.

OBSERVATIONS ON DIFFERENT TREATMENTS

Soils Nos. 9 and 10 are directly comparable. Soil No. 9 has been in a vetch-cotton rotation for 8 years; soil No. 10 has been in cotton without vetch for a number of years and probably no vetch was ever grown on this soil. When used for inoculation, vetch soil No. 9 produced 5,692 pounds of vetch and No. 10 produced 4,104 pounds.

Soil No. 14 came from a spot in the field where cotton died early due to wilt; soil No. 15 came from nearby where the cotton did well. Both soils increased the yields of vetch as if they had an excellent supply of nodule bacteria.

Where basic slag was applied to Austrian winter peas, the yield of vetch when the soil was used for inoculation was increased from 2,556 to 3,165 pounds per acre (soils Nos. 115 and 116).

Soil No. 136 had a very low value for inoculating vetch. It had had one year of good vetch. The good vetch was produced by planting the seed in contact with basic slag which was necessary for the vetch growth.

There was no difference in the value of soils Nos. 131 and 132 when used for inoculation. One of them had one year of vetch; the other had 3 years of vetch.

Soils Nos. 201 and 202 came from the same field, and the main difference between them is that soil No. 201 is a sandy soil and No. 202 is a sandy loam. Soil No. 201 produced 2,914 pounds and soil No. 202 produced 4,240 pounds of green vetch per acre when used to inoculate the vetch.

RELATION OF LONGEVITY OF VETCH NODULE BACTERIA TO CHEMICAL PROPERTIES OF SOIL

The vetch nodule bacteria were apparently not as abundant in soils below a pH of 5.0 as in soils above a pH of 5.0, but many extremely acid soils had an ample supply of nodule bacteria and some soils with a pH above 5.0 had a relatively low quantity of nodule bacteria.

There was no relation between the available phosphorus and soluble iron and the longevity of nodule bacteria.

RELATION OF NUMBER OF YEARS OF VETCH ON SOIL AND LONGEVITY OF VETCH NODULE BACTERIA

There is apparently no relation between the number of years of vetch or the number of years since vetch and the value of the soil for inoculating vetch.

SUMMARY

Ninety-two samples of soil were obtained from fields or woods which had different vetch histories. Fifteen of the soils had never been planted to vetch and no related cultivated plants had been grown. Seventy-seven soils had grown vetch for one or more years, and it had been from none to several years since vetch had been grown. The soil was used to inoculate vetch at the rate of one fruit jar top full (about 60 grams) of soil per 30 feet of row. The soil inoculation was compared to commercial and no inoculation. The data show that:

1. Twenty per cent of soils which had not previously grown vetch and 50% of the soils which had grown vetch, with the quantity of soil used, were probably equal to or superior to commercial culture for inoculating vetch.
2. Twelve of the soils produced over 1,000 pounds more vetch than commercial culture.

3. Vetch nodule bacteria were present in 96% of the soils which had previously grown vetch.

The data suggest that:

1. Sixty-nine per cent of the soils would not need inoculation when vetch is planted on them.
2. Ninety-six per cent of the soils which had grown vetch probably would not need inoculation.
3. Four per cent of the soils which had grown vetch previously would need inoculation.
4. Nodule bacteria apparently do not thrive as well in sandy soils as in heavier soils.

CONCLUSION

Soils which produce a good crop of vetch without the addition of lime in the drill do not need inoculation when vetch is planted on the field again. Soil inoculation where excellent vetch has been grown is equal to or superior to commercial culture.

A heavy suspension of clay from soil which has previously grown good vetch is a satisfactory method of inoculating vetch.

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RETENTION BY SOILS OF THE NITROGEN OF UREA AND SOME RELATED PHENOMENA[1]

JOHN P. CONRAD AND C. N. ADAMS[2]

INTEREST in the application of fertilizers dissolved in the irrigation water has been growing in the western states. Principles governing the behavior of the different nutrient units in the various inorganic fertilizers have for the most part been realized for years. Knowledge of these principles is becoming more widespread among those employing this easy method of fertilizer distribution. The retention of ammonium ions by the soil against leaching and the remaining of nitrates in the soil solution in a leachable form have recently been demonstrated by plant response (3).[3] These studies were inaugurated to extend our knowledge with regard to the organic fertilizer, urea.

Evidence in the literature indicates some small adsorption of urea by colloids, including soil colloids. Van Harreveld-Lake (12) recovered on the average 88% of urea in a 1:2 soil-water extract after 48 hours. In comparative trials 0.5 to 3% of the nitrogen of NH_4Cl and 96 to 100% of the nitrogen of $NaNO_3$ was recovered. He attributed the retention of the urea to adsorption by certain soil constituents, probably humus. Przylecki, *et al.* (10) secured 2 to 5% adsoprtion of urea on animal charcoal from urea solutions of varying concentrations. In comparable tests Grettie (6) secured adsorption of 1.9% of the original urea present on silica, 2.94% on alumina, 0.3% on iron oxide, and 5% on fuller's earth. Kniaseff (9), using Grettie's technic again, secured 5% adsorption on fuller's earth from an aqueous solution of urea, but in alcoholic solution only 0.95%. These observations from other fields of science are of special interest as nearly all of these substances or substances closely resembling them occur in many soils.

In comparative leachability trials with various soluble nitrogenous fertilizers, Benson and Barnette (1) mixed urea with Norfolk sand. After incubation for 1 day, 35.1% of the nitrogen applied as urea was leached out, 35.0% being recovered as urea; after 4 days, 16.4% with 16% recovered as urea; after 10 days, 3.8% with none of it recovered as urea; and after 21 days, 18.7% with all of it recovered as ammonia and nitrate nitrogen. The effect of incubation in transforming urea to ammonium carbonate and in turn into HNO_3, and a few, at least, of the resultant effects on the soil have been worked out in some detail (2, 8).

Two mechanisms seem available to cause the retention of the nitrogen of urea by the soil, *viz.*, a small amount of adsorption by the soil of the urea itself and the transformation of urea to ammonium carbonate followed by the strong retention of the latter.

PRELIMINARY EXPERIMENTS

Preliminary tests to determine experimentally the behavior of urea and $CaCN_2$ were conducted by using the method developed by Crafts (4). A solution of each of these two compounds was allowed

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[2]Associate Professor and Graduate Student respectively.
[3]Figures in parenthesis refer to "Literature Cited", p. 54.

to drip down upon a continuous column of dry soil deficient in nitrogen, in a demountable tube. After the column had been completely wet by the solution, it was sectioned in 6-inch depths, each section placed in a separate pot, and cropped to milo. Table 1 gives the yields of plants secured. The yields decreased with depth with both of these compounds, indicating a reaction between the soil and some of the nitrogen of these compounds as they percolated through it. Citations above indicate a possibly small adsorption of urea, and inferentially the cyanamide ion, by the soil itself. Retention of the rest of the nitrogen held back from solution could be caused by a continuing but rapid transformation to $(NH_4)_2CO_3$ and the strong retention of the latter at or close to the point of change. The larger yields from sections near the bottom are attributed to nitrates leached down.

TABLE 1.—*Nitrogen retention from percolating solutions by continuous columns of Yolo loam as shown by subsequent plant response.*

Percolating solution	Transverse section, depth in feet from top of column							
	0–0.5	0.5–1.0	1.0–1.5	1.5–2.0	2.0–2.5	2.5–3.0	3.0–3.5	3.5–4.0
Urea.......	8.3*	9.2	7.8	5.4	3.9	3.6	4.2	6.0
Calcium cyanamide .	8.0	6.2	4.9	3.4	2.0	2.4	3.6	4.6

*Yields of green milo in grams per pot. Three check pots not fertilized and not subject to percolation averaged 3.1 grams per pot.

To try out microbial transformations as a cause of retention, subsequent percolations at four different temperatures were conducted. One was kept as close to freezing as possible to reduce microbial activity to the minimum, i.e., at 2° C in the cold storage rooms of the Pomology Division; another was kept high enough to be above the thermal limit of activity for urea bacteria, i.e., at about 90° C in a large electrically heated drier; and two were kept at convenient intermediate temperatures about 11° and 40° C. Columns of five pots each were employed using essentially the same procedure as previously described (3). The yields are reported in Table 2. In two soils, Yolo loam and Fresno fine sandy loam, there was evidence which strongly suggested retention of nitrogen at 2° C. The evidence with all three soils showed retention of nitrogen at all other temperatures except 90° C. The percolation at 90° C with Yolo loam suggested very little retention of the nitrogen of urea at that temperature.

Most microbial activity is slowed down to a minimum below 5° C, but Rubentschik (11) has experimented with two organisms that grow and decompose urea below 0° C. If organisms of this type were present and were immediately very active in our percolations, a point that may very seriously be questioned, the results secured might be adequately explained. If such were the case, however, other explanations would not be excluded.

As an alternative these preliminary data, therefore, suggest (a) that there may have been but little adsorption of urea as such by the solid phase of the soil, assuming no change in the adsorption capacity

of the soil by heating to 90° C; (b) that probably during percolation at the lower temperatures, 2° to 40° C, urea gradually but somewhat rapidly hydrolyzed to $(NH_4)_2CO_3$, the latter being strongly retained where it was formed; (c) that the factor causing hydrolysis was practically as effective at 2° C as at the other temperatures and might, therefore, be catalytic rather than microbial; and (d) that the catalyst causing hydrolysis of urea which is inactivated by heating to 90° C could be a hydrolytic enzyme adsorbed on the soil colloids.

TABLE 2.—*Retention by soils of the nitrogen from urea solutions percolated at different temperatures as shown by subsequent plant response.*

Temperature during percolation, °C	Yield of green milo, grams per pot					
	1st pot in column	2nd pot in column	3rd pot in column	4th pot in column	5th pot in column	Check*
			Yolo Loam			
2°	8.4	8.5	4.5	4.1	3.6	2.6
11°	13.4	6.0	3.3	3.4	3.6	
40°	14.2	9.1	5.0	3.7	3.3	
90°	4.5	4.6	5.9	5.8	4.9	
			Imperial Silty Clay Loam			
2°	3.7	3.9	3.4	3.4	2.4	2.2
11°	3.7	5.4	2.8	2.9	1.5†	
40°	12.0	2.6	1.9	2.7	0.0†	
			Fresno Fine Sandy Loam			
2°	10.2	7.0	4.8	6.2	1.8	3.2
11°	5.7	8.0	7.6	6.7	5.2	
40°	8.0	8.1	7.7	7.7	4.6	

*Value for unfertilized and unpercolated pots of same soil.
†Values for second planting; first did not germinate.

REPLICATED PERCOLATION STUDIES

To test the possibility of catalysis, percolations were conducted with various soil treatments. In addition to the checks these were as follows:

1. *Percolation under toluene.*—This antiseptic should inhibit, if not entirely inactivate soil micro-organisms leaving largely catalytic activity remaining. Consequently, columns of pots were set up as described by Conrad and Adams (3) in a garbage can with 10 mls. of toluene added to the dry soil of each pot, and 10 mls. mixed with each solution before percolation. Except as operations momentarily required, the garbage can was kept covered. A strong odor of toluene was evident each time the lid was removed.

2. *Percolation with preheated soil.*—The results of the percolation at 90° C suggested a heat inactivation of the catalytic agent or enzyme. If this was so, preheating of the soil prior to carrying on percolation and then subsequent percolation at normal temperatures should be equally effective. In preheating, a lot of the normal soil was moistened with distilled water in a crock and placed for 48 hours

in a chamber maintained between 80° and 90° C. After this time, the soil was spread out and dried at this same temperature. This soil was stored dry as a stock lot and was handled in the same manner as the untreated dry soil. Actually this soil was slightly drier as stored than the normal soil and, therefore, in weighing out the respective lots, a little more actual oven-dry soil was obtained. In percolating these pots with the various solutions, the preheated soil, therefore, gave less volume of percolate than the others.

Again, if the transformations in the soil are catalytic, a slower rate of percolation should give a greater difference in the resulting growth between the pots in a column; therefore, two rates of percolation were tried as follows:

1. *Rapid.*—The solution was added as rapidly as it would penetrate the soil. In each case, all of the solution had disappeared from the surface of the top pot in 7 hours or less.

2. *Slow.*—In this case, each solution was added to its respective column in five nearly equal portions, applied approximately 12 hours apart. The columns under toluene received solutions over a period of 49 hours; the other columns, over a period of 44½ hours. In an additional two or three hours, most of the excess solution undoubtedly drained down; however, the columns were allowed to stand for an-

TABLE 3.—*Retention by Yolo fine sandy loam of the nitrogen from solutions of urea percolated at two rates and through soil variously treated, as shown by the yields of the subsequent green growth of milo.*

Soil treatments	Yield of green milo, grams per pot							
	Rapid percolation, about 7 hrs.				Slow percolation, about 50 hrs.			
	1st pot in column	2d pot in column	3d pot in column	Column number	1st pot in column	2d pot in column	3d pot in column	Column number
				Urea				
None	13.8[1]	11.3	9.9[4]	4	15.9[3]	13.4[2]	6.0	3
Percolation under toluene	15.2[3]	12.7[2]	9.7[4]	4	13.2	13.1[1]	6.2	3
Preheating to about 85°C	14.9	15.0[1]	12.2[5]	3	15.1	14.6[2]	11.8[5]	5
				Distilled water[6]				
None	2.1	1.8	1.8	5	—	—	—	—
Percolation under toluene	2.3	2.5	2.2	4	—	—	—	—
Preheating to about 90°C	3.0	3.5	3.6	5	—	—	—	—

Statistically different (5, p. 112) from the value to the right and from the pot next below it in the column.
[1]P = 0.01 or less
[2]P lies between 0.01 and 0.02
[3]P lies between 0.02 and 0.05
Statistically different, P = 0.01 or less, (5, p. 114)
[4]From the values for the 3rd pots of the corresponding columns percolated slowly.
[5]From the two values immediately above.
[6]All values for the urea treatments, P less than 0.01, (5, p. 114) greater than corresponding values for distilled water.

other 24 to 36 hours before being dismantled. Each column was percolated with 500 mls. of total solution. The urea solutions contained 20 m.at.N[4] per liter or 10 m.at.N per column.

As toluene might be injurious to crop growth, the pots were allowed to aerate for about a week. They were then all cropped to milo and otherwise handled as reported previously (3). The yields secured are given in Table 3, and the cultures are illustrated in Fig. 1.

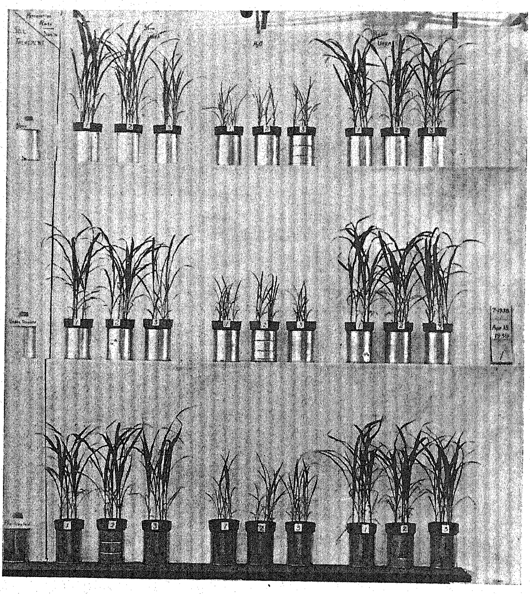

FIG. 1.—Effect of soil treatments and rates of percolation on the retention of the nitrogen of urea by Yolo fine sandy loam. Each group of 3 pots, marked 1, 2, and 3 were staked in a column and subjected to a percolating solution. All groups on the left were percolated slowly with urea; all groups on the right, rapidly with urea; and all groups in the center, with distilled water. The soil used for the cultures shown in the top tier was untreated; in the center tier, soil under toluene; and in the bottom tier, preheated soil.

At the time the percolation columns were dismantled, the percolates were measured and later analyzed for the concentration of urea

[4]Milligram atoms of nitrogen.

in each, Marshall's urease method as described by Hawk and Bergeim (7, p. 712) being used. Table 4 reports these data.

TABLE 4.—*Average volumes and concentrations of urea in percolates from columns for data in Table 3.*

Soil treatment	Rate of percolation			
	Rapid		Slow	
	Volume, mls.	Concentration of urea, m.at.N per liter*	Volume, mls.	Concentration of urea, m.at.N per liter*
None	97	1.35	70	0.07
Percolation under toluene	78	0.43	69	0.03
Preheated to about 85°C.	44	1.54	13	0.48

*The urea solutions added to the top of the columns contained 20 m.at.N (milligram atom of nitrogen) per liter.

The data of Table 3 disclose no significant differences between the results secured with and without toluene. Both normal soil and soil under toluene showed significant retention of nitrogen in the upper parts of the column. In every case, the bottom pots gave significantly lower yields than one or more pots above them. This was especially significant where the urea was percolated through slowly. Likewise, with the preheated soil, the bottom pots yielded significantly less than the middle pots of the column. The bottom pots of the normal soil and those percolated under toluene yielded significantly less than the bottom pots of the preheated soil. The rates of percolation with preheated soil apparently had very little effect upon the retention of the nitrogen of urea. The rate of percolation, however, with normal soil and that under toluene had a marked effect on the distribution of nitrogen. The yields of the bottom pots where percolation had been rapid were significantly higher than the yields of the bottom pots where percolation had been slow.

These data constitute good evidence that the transformations of urea in the soil, at least in so far as that which takes place during the relatively short time of percolation, was largely catalytic rather than microbial. Further evidence supporting this view is being gathered in a laboratory study, a report on which will be given later.

SUMMARY

1. In preliminary studies in which urea solutions were percolated through columns of dry soil and then the columns subsequently sectioned, the response of milo was used to indicate the final distribution of the nitrogen applied in the urea. Untreated soils progressively removed at least some of the nitrogen of urea and of $CaCN_2$ from solutions as they percolated through them. This property of the untreated soils was largely lost by percolating urea at 90° C, but persisted at 2°, 11°, and 40° C.

2. Though a small amount of adsorption and unusually great microbial activities might account for these data, an alternate explanation is a catalytic hydrolysis (independent of micro-organisms) of urea to ammonium carbonate during percolation with the subsequent strong retention of the latter.

3. To test the possibility of catalysis in the hydrolysis of urea, percolations were conducted with various soil treatments. No significant differences in the growth responses between the untreated soils and those percolated under toluene were disclosed. Significantly smaller amounts penetrated to the lowest pots of the columns with these two treatments than with soil preheated in a moistened condition to about 85° C and subsequently dried before percolation. A slower rate of percolation significantly decreased the amount of nitrogen reaching the lowest pots with the untreated and toluened soils, but not with the preheated soil.

4. The growth results as well as the analyses of the small amount of percolates from the columns are in agreement with the hypothesis that adsorption and a thermolabile catalysis were perhaps largely responsible for the retention of the nitrogen of urea by the untreated soil.

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THE SEGREGATION OF GENES AFFECTING YIELD OF GRAIN IN MAIZE[1]

Merle T. Jenkins[2]

PRESENT-DAY maize breeding in the United States involves isolating self-fertilized lines, testing them, primarily for yield, in hybrid combination, and then utilizing the superior ones in F_1 hybrids of one kind or another. The value of the different inbred lines in the breeding program depends upon their general contributions to their hybrid progeny and particularly to the value of specific individual hybrids involving them. Experience has demonstrated these two characteristics to be correlated and that inbred lines imparting a high average yield to their hybrid progeny may be expected also to produce high yielding individual hybrids. Accordingly, it has become practice to test new inbred lines in top crosses, i.e., crosses with an open-pollinated, heterozygous variety, using the top-cross data as a measure of their ability to impart high average yield to their hybrid progeny, or, more conveniently, their yield prepotency.

Yield prepotency depends, of course, upon the number of dominant alleles favorable to yield carried by the different inbred lines and upon their relative importance. The rate at which fixation for yield prepotency occurs in an inbreeding program likewise is dependent upon these two factors. In an experiment reported by the writer in 1935 (2),[3] it was found that inbred lines of corn showed their individuality as parents of top crosses very early in the inbreeding process and remained relatively stable thereafter. This rather surprising situation was explained on the basis that yield was controlled by a large number of dominant genes, many of which have approximately equal effects. Essentially equal numbers of dominant alleles will be preserved by chance through the successive generations of selfing even though accompanied by segregation for particular dominant alleles. These data are all that are available in maize (or in any other organism so far as is known to the writer) on segregation for yield prepotency. They do not permit a precise determination of the amount of segregation for various reasons.

From the standpoint of practical corn breeding, it is important to know the earliest possible generation in which newly developed lines may be tested for yield performance. Early elimination of unpromising lines permits a concentration of effort on more promising material and should result in greater progress in the breeding operations.

It was decided, therefore, to obtain data on which a more precise estimate of the segregation for yield prepotency might be based. Two assortments of the genes influencing yield will affect the segregation for yield prepotency. When a maize plant heterozygous for many pairs of yield genes is self pollinated, the complement of genes re-

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[3]Figures in parenthesis refer to "Literature Cited", p. 63.

ceived by the different plants comprising its inbred progeny will vary in the number and in the particular dominant alleles present. When these progeny plants are used individually as the parents of top crosses, both the number of dominant alleles they contribute and the importance of the particular dominant alleles contributed will affect the performance of the resulting top cross. These two effects cannot be measured separately, but their combined value may be measured by the segregation for yield prepotency which they produce.

The first generation of inbreeding was chosen as the best one in which to obtain data on segregation for yield prepotency as it is greatest in this generation of inbreeding. The heterozygosis present in the original parents of the inbred lines will decrease in accordance with the series ½, ¼, ⅛, etc., with successive generations of selfing. With data available on the first generation of inbreeding, therefore, segregation in later generations may be computed readily. Using this information as a basis, it should then be possible to arrive at a reliable estimate as to the number of generations of selfing required to reduce segregation to a point at which the amount remaining offers little practical opportunity of extracting sub-lines that differ materially from the mean for the line in yield prepotency.

THE EXPERIMENT

Seven lines of Krug which had been selfed for one generation were selected as the parent lines in which segregation was to be determined. These lines came from among a group of 37 Krug lines first inbred at Ames, Iowa, in 1926. The lines were top crossed with the parent variety in 1929 after they had been inbred for three generations and the top crosses were compared for yield in 1930. Thirteen of the more promising lines were saved, new top-crossed seed was produced after succeeding generations of inbreeding, and the top crosses compared for yield and other characters. Three of the 13 lines were discarded after tests running through 1932. Top crosses of the remaining 10 lines were tested for a fourth time in 1933. The data on the acre yields of the top crosses of these 10 lines are shown in Table 1. The seven lines chosen for the present experiment are indicated in this table.

TABLE 1.—*Acre yields of top crosses between inbred lines of Krug and the parent variety.*

Inbred line	Acre yields in the season indicated				
	1930	1931	1932	1933	Mean
K675	40.0	71.9	77.2	73.6	65.7
K679*	39.7	75.8	71.3	80.9	66.9
K680	42.3	67.0	67.7	77.4	63.6
K682*	37.3	74.6	81.8	92.3	71.5
K683*	51.9	81.1	77.6	84.3	73.7
K685*	22.4†	70.4	74.7	79.2	61.7
K686*	37.9	79.8	79.5	86.3	70.9
K687*	31.1†	79.5	66.1	73.6	62.6
K689*	36.2	76.4	71.7	82.0	66.6
K690	49.9	81.8	87.4	88.0	76.8
Krug	37.5	76.5	75.1	79.9	67.3

*Inbred lines included in the present experiment.
†Sister progeny of the one tested in the later generations.

Average yields of the top crosses of the lines chosen ranged from 5.6 bushels below to 6.4 bushels above the yield of the parent variety. As far as the relative heterozygosity of the open-pollinated plants is concerned, they represented an entirely unselected population as nothing was known about them in this regard.

Remnant S_1 seed of the seven chosen lines was planted at Arlington Experiment Farm, Arlington, Virginia, in 1936 in ear rows 25 plants in length. Pollen was collected individually from at least 16 plants from each ear row, the pollen from each plant being applied to the silks of 25 plants of the Krug variety. No conscious selection was practiced either among the plants within the ear rows or among plants of the Krug variety. There may have been some natural selection, however, in favor of the surviving plants in the ear rows which failed to have 25 plants reach pollen shedding. Seed representing each top cross was prepared by mixing equal numbers of seeds from not less than 20 of the 25 ears pollinated with pollen from that plant.

The top crosses of the 112 individual inbred plants on Krug were compared for yield in 1937 on a very uniform piece of land near Columbus, Ohio, provided through the courtesy of the Dairy Husbandry Department of Ohio State University. Six seeds were dropped per hill and the plots later were thinned to three plants per hill. Ten replications of plots 2 by 10 hills were grown of each entry in the yield test. The test was laid out in 10 blocks, one block for each replication. Within each block the entries were arranged in seven groups of 16. Each group of 16 entries comprised the top crosses of the 16 sibling plants of one inbred line. The entries were distributed at random within the groups of 16 and the seven groups were distributed at random (with restrictions to equalize the distribution of the groups among seven columns of groups) within the blocks. Acre yields were computed on a basis of shelled grain with 15.5% moisture.

EXPERIMENTAL RESULTS

The acre yields of the 112 top crosses included in the test are shown in Table 2. In order to illustrate the segregation for yield prepotency in hybrids, the data are shown graphically in Fig. 1. In this figure the yield of the top cross of each plant is expressed as a deviation from the mean of the top crosses of the group of 16 sibling plants of the same line. The general mean acre yield for all groups was 62.7 bushels.

The analysis of variance of the acre yields is shown in Table 3. The variances among lines and among sibling plants within lines both are highly significant. We are most concerned here with the variance among siblings within lines, that is, with the average variance among the top crosses of the 16 sibling plants within each of the seven lines, each selfed for one generation. This variance of 77.21 is comprised of two portions, the error term (19.97) and the variance among sibling plants within lines (57.24). On the basis of theory the variance among the siblings within lines will successively be reduced in accordance with the series ½, ¼, ⅛, etc., in successive generations of selfing, while the error term will remain unchanged. Accordingly, the appropriate mean squares for the first eight generations of inbreeding were computed and are shown in Table 4.

The data in Table 4 indicate that under conditions similar to those of this experiment it should be possible to demonstrate significant segregation for genes affecting yield prepotency in hybrids in the

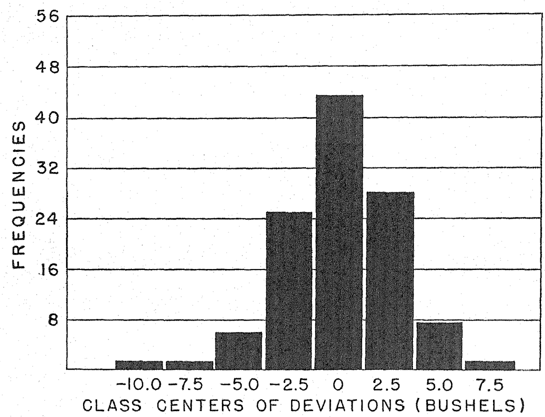

FIG. 1.—Frequency histogram of the deviations in acre yield of the top crosses of 112 S_1 plants from the means for their respective lines.

TABLE 2.—*Acre yields of grain in bushels for 112 Krug top crosses grown near Columbus, Ohio, 1937.*

Plant No.*	Acre yields in bushels of top crosses with plants of the inbred line indicated						
	K679	K682	K683	K685	K686	K687	K689
1	65.4	66.1	60.0	61.8	59.1	58.3	64.4
2	67.5	65.5	64.6	61.9	66.6	63.1	65.3
3	66.3	64.8	62.1	62.0	62.3	63.9	63.9
4	65.9	68.6	64.2	60.2	62.0	60.7	61.8
5	64.6	65.7	60.7	56.0	59.1	65.3	62.7
6	68.2	65.1	64.7	52.2	63.3	61.5	63.8
7	64.4	63.6	60.8	57.0	61.0	66.6	64.7
8	62.7	64.7	60.9	58.3	55.8	59.8	61.7
9	63.1	62.7	63.2	59.8	65.2	61.6	62.8
10	68.6	63.7	67.4	62.7	59.5	64.1	59.8
11	62.8	63.8	61.8	59.5	63.7	64.9	64.0
12	54.6	61.0	59.4	58.3	61.9	69.4	62.7
13	66.0	64.6	61.6	54.8	58.7	65.7	57.5
14	65.7	61.7	64.9	57.9	55.8	60.0	63.9
15	64.5	67.2	66.7	59.1	62.7	67.1	63.5
16	62.5	63.7	64.0	56.9	68.4	66.0	64.5
Group means	64.6	64.5	62.9	58.7	61.6	63.6	62.9

*Consecutive plant numbers of the plants from which pollen was collected; not necessarily the actual plant numbers within the rows.

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seventh generation of selfing. The parental plants in the S_6 generation had on an average only 1.56% of the genes that were segregating in the original plant still in the heterozygous condition.

TABLE 3.—*Analysis of variance of the acre yields of top crosses of individual plants in one-generation Krug selfs, Columbus, Ohio, 1937.*

Source of variation	D/F	Sums of squares	Mean squares	F
Lines	6	4,081.93	680.32	34.07*
Sibling plants within lines	105	8,107.39	77.21	3.87*
Replications within lines	63	25,417.51	403.45	20.20*
Error	945	18,871.33	19.97	——
Total	1,119	56,478.16		

*Highly significant.

TABLE 4.—*Variance and standard deviations among the acre yields of top crosses of sibling plants in successive generations of selfing, computed from the variance determined for the first generation.*

Generation	Hetero-zygosity* %	Mean square	F	Standard deviation (bu.)
Original plants	100.00	——	——	——
S_1	50.00	77.21	3.87†	2.8
S_2	25.00	48.59	2.43†	2.2
S_3	12.50	34.28	1.72†	1.8
S_4	6.25	27.13	1.36†	1.6
S_5	3.13	23.55	1.18†	1.5
S_6	1.56	21.76	1.09†	1.5
S_7	0.78	20.86	1.04†	1.4
S_8	0.39	20.42	1.02	1.4
Error		19.97		

*Average heterozygosity of the plants within the generation indicated which in turn is reflected in the variability among the plants of the generation following. The heterozygosity actually present in the original plants is taken as 100%.

†Highly significant.

From the standpoint of practical plant breeding, however, the segregation must be large enough to offer reasonable chances for the accomplishment of improvement by selection. A statistical demonstration that segregation exists is of no value in itself. Table 4 shows the standard deviation for yield in the first generation of inbreeding to be 2.8 bushels per acre. Within the first generation of inbreeding, therefore, the top crosses of two-thirds of the segregates should fall within 2.8 bushels of the mean for the line and there should be only 1 chance in 40 of obtaining a segregate whose top cross exceeds the mean of the line by as much as twice the standard deviation, or 5.6 bushels. This is only 8.9% of 62.7 bushels, the mean yield of all top crosses in the experiment. In a great majority of the general run of yield tests with corn having the usual five or six replications, differences as small as this are not significant statistically.

A reasonably low standard deviation in the first generation was anticipated on the basis of the earlier data (2); however, a standard

deviation as low as the one actually computed from these data was not expected. These results indicate that the segregation for yield prepotency among the plants within the first generation of inbreeding was so limited that the opportunity of selection for this character within lines even in this generation would not have been very promising. The envisioned computation of a later generation possessing the desired amount of stability, therefore, is superfluous.

Had these results been anticipated, the experiment would have been designed to permit a direct comparison of the segregation for yield prepotency occurring among plants of the parent open-pollinated variety as contrasted with that among sibling plants within lines selfed for one generation. Such a comparison would permit a computation of the relative emphasis that efforts on selection in the two classes of material should most profitably receive.

In the absence of a critical experiment especially designed to permit a comparison of this kind, the writer cast about for data on the segregation for yield prepotency occurring among plants of a variety which might be compared with these on segregation within one-generation selfs. No suitable data are available in the literature. The ear-to-row tests of previous years should have provided information on this subject, as they were in reality yield tests of the top crosses of individual plants with the variety, the individual plants serving as female parents. These early tests, however, were not designed in such a manner as to permit of statistical analysis.

A few data are available from another experiment also conducted by the writer in 1937 but for an entirely different purpose. This experiment comprised an ear-to-row yield test of open-pollinated ears of corn harvested from two-eared plants of the Krug variety. The test was grown on Arlington Experiment Farm. There were six replications of single-row plots 14 hills in length with three plants per hill. The experiment contained 36 entries, 35 ear rows, and one entry of the Krug variety. The analysis of variance for acre yields is shown in Table 5.

TABLE 5.—*Analysis of variance of acre yields of top crosses on 2-eared Krug plants, Arlington Experiment Farm, 1937.*

Source of variation	D/F	Sums of squares	Mean square	F
Blocks	35	3,267.824	93.366	1.59*
Ear rows	35	11,142.046	318.344	5.43†
Error	145	8,504.586	56.652	
Total	215	22,914.456		

*Significant.
†Highly significant.

The variance among ear rows in Table 5 can not be compared directly with that in Table 3 as the level of productivity in the two experiments differed rather widely. The pertinent data from the two experiments are assembled in Table 6. They indicate much greater segregation among the plants of the variety than among the siblings within one-generation selfs, but they do not permit a precise comparison.

TABLE 6.—*Comparison of the variability in the yield of top crosses of plants of the Krug variety and plants in first-generation Krug selfs.*

Material	Mean squares	No. of plots	Variance	Standard deviation (bu.)	Mean yield (bu.)	Coefficient of variability
Open-pollinated plants within the Krug variety	318.344	6	53.057	7.3	91.1	8.0
Sibling plants within the first generation of selfing	77.21	10	7.721	2.8	62.7	4.5

These data further emphasize the greater chances of obtaining lines of outstanding performance in hybrids through selection *among* large numbers of inbred lines rather than *within* lines. They also add to the accumulating evidence indicating that the yield prepotency of lines in hybrids, as measured by their top crosses, may be determined very early in the inbreeding period.

SYNTHETIC VARIETIES FROM SHORT-TIME INBRED LINES

On the basis of the 1935 data previously mentioned (2), which indicated that inbred lines became stable for yield prepotency early in the inbreeding period, the writer has informally suggested the possibility of producing synthetic varieties among short-time inbred lines for use in sections where hybrid corn may not be economically feasible. As the data presented here indicate even less segregation within lines than those obtained earlier, they seem to emphasize the possibilities of the method and a description of it may be worth while at this time.

Hybrid corn has become definitely established in the Corn Belt and doubtless will be used extensively there until a more efficient breeding method is developed. There are many sections around the margins of the major corn-producing areas, however, where growing conditions are severe and the development and maintenance of inbred lines and the production of hybrid seed corn is a more hazardous and expensive undertaking. It is questionable whether the use of hybrid corn will become an established practice in some of these sections.

The early individuality and stability of inbred lines for yield prepotency would seem to permit of their use in a breeding procedure that should insure more productive varieties than can be obtained by any of the modifications of mass selection now in use. The procedure contemplated involves the production of synthetic varieties among short-time inbred lines. The essential steps in the procedure are:

1. The isolation of one-generation selfed lines.
2. Testing of these lines in top crosses for yield and other characters to determine their relative endowments with respect to genes affecting these characters.
3. Intercrossing of the better-endowed selfed lines to produce a synthetic variety.

4. Repetition of the above process at intervals after each "synthetic variety" has had a generation or two of mixing, possibly with the inclusion of lines from unrelated sources.

There are many ways in which the above procedure may be carried out. For example, the one-generation lines may be produced, planted in a field of the parent variety, and detasseled in order to obtain top-crossed seed. Or the initial plants may be double-pollinated for the production of selfed and crossed seed on the same ear as suggested by Sprague (4). If the parent variety happens to be a prolific variety, one of the ears on the plants may be selfed and another used for crossing, or the additional ear or ears may be allowed to open-pollinate. The latter actually is the procedure that was followed in the case of the experiment with the two-eared Krug plants previously described.

The method has some superficial similarity to the older ear-to-row method of breeding. It differs fundamentally from the ear-to-row method, however, in that the germ plasm of the tested plants is maintained by selfing the plants and this selfed seed of the superior individuals is mixed and increased in developing the new strain. In the ear-to-row method of breeding, the male parentage of the selected plants was not controlled and as a result represented the variety average.

It is envisioned that the procedure outlined should be a more or less continuous one, with improved varieties or strains released to growers as they are obtained. A sufficient number of lines should be included in each synthetic strain to permit growers to select seed from it by mass selection during the interval of 3 to 4 years required to complete the next cycle of isolating lines, testing them in hybrids, and recombining the selected lines into a new synthetic strain to replace the old one. Experience will have to determine the minimum number of lines necessary for this purpose. It would seem, however, that there should not be less than about 10.

Jenkin (1) coined the term "strain building" to describe the methods he employed in breeding perennial rye grass which resemble in some particulars the procedure outlined above. The term was used by him and later by Kirk (3) in a very broad sense to include any system of mating by which a strain is built up by crossing from carefully selected plants. The parental plants usually were selected on the basis of a progeny test, but no particular distinction was made between the use of inbred or crossbred progeny for testing purposes. Ample experience in corn indicates that the performance of inbred lines as such is not highly correlated with their performance in hybrids, and the use of a broad term which gives no implication of the kind of testing procedure could not be recommended for this crop.

There are hardly sufficient data available on synthetic varieties in corn to form much of a basis for estimating the possibilities of improvement through the use of such synthetics among short-time lines. On the basis of theory, however, the use of such synthetics should definitely offer promise of greater improvement than can be accomplished by simple mass selection. The method, however, is not suggested for areas where hybrid corn is economically feasible.

SUMMARY

1. The segregation of genes affecting yield of grain in maize, as reflected in the differences among the individual plants to impart high average yield to their hybrid progeny, was determined in the first selfed generation of seven plants of the Krug variety. The ability of the plants to impart high average yield to their hybrid progeny, or, more conveniently, their yield prepotency, was measured by testing the top crosses between the individual plants and the parent variety.

2. The average standard deviation among the top crosses of individual plants within the seven S_1 populations was 2.8 bushels per acre, indicating only 1 chance in 40 of obtaining a plant within this generation whose top cross would yield 5.6 bushels or 8.9% above the mean for the line.

3. The limited segregation for yield prepotency permits, and emphasizes the importance of, early testing of the lines to determine their relative endowment with respect to factors affecting yield.

4. A method of breeding involving the production of synthetic varieties among short-time inbred lines is suggested for areas where hybrid corn may not be economically feasible.

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THE RELATIONS OF COLOR TO GERMINATION AND OTHER CHARACTERS OF RED, ALSIKE, AND WHITE CLOVER SEEDS[1]

D. C. SMITH[2]

WHILE assisting with crops judging work at Oregon State College the writer's attention was attracted to the question of relative values of the various seed colors in red, alsike and white clovers. It had been assumed that darker shades of purple were preferable in red clover seed and similarly that the darker shades of black or green in alsike clover were most desired. Bright yellow color was thought to be most sought for in white clover. Since few data seemed available in the literature the bases for these assumptions were uncertain.

In 1912, Gernert (3)[3] wrote that, "There is a popular demand for purple-colored clover seed, the general impression being that purple color indicates maturity, viability and vigor. It is quite well established that purple in clover seed has no relation to yield, either of seed or hay."

Eastman (2) in the same year, observed that, "Farmers, and consequently seedsmen, prefer seed of a dark color because they believe it looks more mature and appears richer in food material."

Recently responses to a letter of inquiry sent to four large northern seed companies of the Middle West and East, dealing extensively in clover seed, indicated agreement to exist as to the general preference for darker colored lots in red and alsike clovers, while in white clover yellow-colored seed was thought to be preferable. These choices were admittedly based to a large extent on attractiveness to the eye of the prospective buyer.

Inquiry was also made of several agronomists in middle western clover seed producing states. Purple-colored seeds in red clover were thought to be more desirable from the trade viewpoint, though it appeared questionable if any fundamental cultural basis for this existed. The possible relation of purple color to maturity, plumpness, and hard seed percentage was suggested. One agronomist expressed belief in existence of a preference for medium dark seed in alsike clover, and others presented the view that dark seeds would be preferred. It appeared to be a general belief that yellow color in white clover was preferable to brown or reddish shades.

The brief experiments discussed here were completed before inquiries were made of seedsmen and agronomists. Though originally planned and finished as a test using few samples and small quantities of seed from one locality, it is thought that the results obtained may be of interest.

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[3]Figures in parenthesis refer to "Literature Cited", p. 71.

REVIEW OF LITERATURE

Many studies have been made upon the relations of viability, hard-seededness, and longevity of clover seed. Reference to these have been omitted except as they relate specifically to color comparisons. The relations of seed size to later growth in clovers and other plants have been subjects for numerous experiments not reviewed here.

Miller and Pammel (4), in experiments with red and white clovers, as well as with other seeds, observed higher germination to occur in large seeds. Eastman (2) compared weights of purple and yellow seeds in 14 samples of red clover. In every sample purple seeds averaged more in weight than yellow. Von Rümker, cited by Eastman (2), found yellow seeds to be heavier than others in red clover. Dymond (1) reported that in only one sample of 85 did yellow seeds of red clover exceed purple in weight. Intermediate colors averaged about the same in weight as purple.

Williams (5) reported the results of extensive experiments in the analysis of color and other characters in red clover seed samples. The literature, reviewed by the same writer, indicated considerable disagreement to exist in results of studies on the relation of color to weight. Most workers observed yellow seeds to be inferior in weight, while some reported no relation to exist. Williams' results agreed with the latter in this respect though large variations were noted among varieties. Purple seeds were found to be generally heavier than yellow seeds from the same plants. No relation was observed between rate of germination and seed weight in red clover.

Germination of purple and yellow seeds in 14 lots of red clover by Eastman (2) showed a higher average percentage of germination and a lower proportion of hard seeds for the purple color. Statistical examination of the data indicates that the average differences were not significant. Preyer, cited by Eastman (2), observed light-colored seeds to germinate much better than the darker seeds. Dymond (1) noted no significant differences among purple, intermediate, and yellow seed colors in red clover as to germination and hard seeds when tested 8 months after harvest.

EXPERIMENTAL METHODS

Five lots each of red, alsike and white clovers were used in these studies. The samples were obtained from seed laboratory lots reduced in size using a Boerner sampler. All of the samples were grown in Oregon the previous season, being about 7 months from harvest when the tests were made. The white clover was of the Ladino variety. They were commercial lots harvested, threshed, and cleaned by ordinary farm machinery. The quality of the samples, judging by purity and appearance, was somewhat better than average for such seeds. The aliquots studied ranged from 3.4 to 5 grams, 1.3 to 3.0 grams, and 2.1 to 3.3 grams in red, white and alsike clovers, respectively.

Four color separations were made in each clover species. All normal seeds in each lot were grouped in one or another of these classes. Brown or shrunken seeds were discarded in red and alsike and shrunken seeds were eliminated in white clover. The limits of each color group were established arbitrarily with the effort being made to keep the ranges similar in each of the several samples separated.

Red clover was divided into purple, yellowish-purple, purplish-yellow, and yellow classes. The intermediate groups were those predominantly one color but not entirely so. Similarly, alsike clover seed was classified as black, greenish-black,

blackish-green, and green. The white clover color separations were red, yellowish-red, reddish-yellow, and yellow.

Germination tests were made on blotters and in soil in a standard germinator at a room temperature fluctuating near 20° C. The seeds on moistened blotters were allowed to germinate 5 days and notes were taken on the third and fifth days. The soil germination tests were made in small paper boxes, seeds being covered approximately ¼ inch deep in a sterilized sandy soil. Observations were recorded 5, 7, and 12 days following seeding.

Duplicate germination tests of 100 seeds were made on blotters and each color class in each seed lot was studied separately. Seeds from the same color classes of the several lots were bulked for the soil germination test and seeded in quadruplicate. Germination on blotters was recorded on the basis of total and weak sprouts. "Hard" seeds were also noted. The latter were considered to be those remaining ungerminated and without signs of decomposition at the end of the period, whatever the reason.

The data for the germination tests on blotters were practically indentical at the third and fifth days. Consequently, only the percentages for five days have been considered. The percentages of germination at 12 days have been included for the tests in soil. Though 5- and 7-day observations were obtained, no distinct differences were observed. Similarly, data on weak seedlings have been omitted since color differences were, for the most part, insignificant.

The analysis of variance was used in the reduction and summary of the data. Twice the standard error of a difference has been taken as the least significant value. Tabular details of the analysis have been omitted to allow brevity.

RESULTS

RED CLOVER

Summary data for red clover are listed in Table 1. Considering weight of seeds, the least significant mean difference was 0.005 gram. Purple seeds were significantly heavier than purplish yellow and yellow seeds and yellowish purple exceeded yellow in this respect.

The least significant difference among colors in total blotter germination was 11.0%. In this respect yellow, purplish-yellow, yellowish-purple, and purple ranked in the order given, all other colors being significantly higher than purple. The value of F indicated a significant difference to exist among lots.

Significant differences existed among the several colors in proportions of hard seeds, with a least significant difference of 15.9%. The percentages of hard seeds in the purple class were significantly higher than those for lighter colors. The interaction of colors and lots was also significant.

The values for soil germination in Table 1 are comparable only for the averages of the color groups since the lot identity, as previously indicated, was not maintained in these tests. In the soil tests error exceeded other components of variation, no significant differences being indicated among colors.

In order of percentage occurrence in the samples the colors ranked yellowish-purple, purplish-yellow, yellow, and purple.

TABLE 1.—*Summary data of color separations and germination percentages in red clover seed samples.*

Lot No.	Weight in grams per 100 seeds	Blotter germination, %		Soil germination, %*
		Total	Hard seeds	
		Purple		
1	0.148	54†	46†	81
2	0.148	40	60	75
3	0.148	91	9	66
4	0.169	40	60	61
5	0.181	40	60	—
Ave.	0.159	53	47	71
		Yellowish Purple		
1	0.148	60	40	75
2	0.147	76	24	68
3	0.148	93	7	80
4	0.170	73	27	68
5	0.174	80	20	—
Ave.	0.157	76	24	73
		Purplish Yellow		
1	0.144	67	33	65
2	0.141	71	29	66
3	0.140	92	8	82
4	0.171	80	20	72
5	0.167	81	19	—
Ave.	0.153	78	22	71
		Yellow		
1	0.141	68	32	61
2	0.137	71	29	71
3	0.131	96	4	79
4	0.171	81	19	76
5	0.167	79	21	—
Ave.	0.149	79	21	72

*Each mean an average of four tests on composite color lot.
†Each value an average of duplicate tests.

ALSIKE CLOVER

In Table 2 summary data for alsike clover seed are given. Black, greenish-black, blackish-green, and green rank as listed in order of decreasing seed weights. The least significant difference was 0.0012 gram. The three darker-colored groups differ significantly from each other.

The least significant difference in blotter germination was 23.47%. Black and greenish-black were similar and significantly higher than green in total germination. Blackish-green was considerably higher than green. An interaction between colors and lots was indicated by the F value obtained.

TABLE 2.—*Summary data of color separations and germination percentages in alsike clover seed samples.*

Lot No.	Weight in grams per 100 seeds	Blotter germination, %		Soil germination, %*
		Total	Hard seeds	
		Black		
1	0.066	64†	36†	78
2	0.076	89	11	79
3	0.070	69	31	66
4	0.071	93	7	70
5	0.070	90	10	—
Ave.	0.071	81	19	73
		Greenish Black		
1	0.063	61	39	73
2	0.073	90	10	67
3	0.068	78	22	75
4	0.069	94	6	81
5	0.067	92	8	—
Ave.	0.068	83	17	74
		Blackish Green		
1	0.058	62	38	64
2	0.072	37	63	62
3	0.065	35	65	58
4	0.064	91	9	62
5	0.066	86	14	—
Ave.	0.065	62	38	62
		Green		
1	0.058	32	68	71
2	0.068	50	50	65
3	0.064	39	61	71
4	0.063	60	40	64
5	0.065	36	64	—
Ave.	0.064	43	57	68

*Each mean an average of four tests on composite color lot.
†Each value an average of duplicate tests.

Variations in percentages of hard seeds in the color lots were significant. The least significant difference was 26.22% with green notably different and significantly exceeding other colors.

The value of F for colors in germination in soil exceeded the .05 point, the least significant difference being 6.84%. Accordingly, only the blackish-green group was significantly different, being lower among the color classes.

In percentages of the different colors greenish-black, black, blackish green, and green occurred in decreasing frequency.

WHITE CLOVER

Summary data for white clover are given in Table 3. The colors rank as red, reddish-yellow, yellowish-red, and yellow in average weight with a least significant difference of 0.0013 gram.

TABLE 3.—*Summary data of color separations and germination percentages in white clover seed samples.*

Lot No.	Weight in grams per 100 seeds	Blotter germination, %		Soil germination, %*
		Total	Hard seeds	
Red				
1	0.049	33†	47†	51
2	0.069	76	24	51
3	0.048	52	48	41
4	0.056	50	50	51
5	0.055	57	43	—
Ave.	0.056	58	42	61
Yellowish Red				
1	0.047	61	39	63
2	0.069	83	17	65
3	0.047	51	49	62
4	0.055	54	46	66
5	0.054	57	43	—
Ave.	0.054	61	39	65
Reddish Yellow				
1	0.051	67	33	57
2	0.069	97	3	63
3	0.046	56	44	59
4	0.055	64	36	61
5	0.053	55	45	—
Ave.	0.055	68	32	59
Yellow				
1	0.041	74	26	73
2	0.067	97	3	78
3	0.045	69	31	75
4	0.053	73	27	70
5	0.052	65	35	—
Ave.	0.052	76	24	74

*Each mean an average based on four tests of composite color lot.
†Each value an average of duplicate tests.

Colors were significantly different in blotter germination, rating in the order of yellow, reddish-yellow, yellowish-red, and red. The least significant difference was 7.52%. Lots differed significantly.

Red, yellowish-red, reddish-yellow, and yellow ranked in order in percentage of hard seeds, with a least significant difference of 6.76%.

Under soil germination conditions colors differed significantly in total seeds sprouted, with a least significant difference of 4.81%. Dif-

ferences between yellow and other colors and between yellowish-red and reddish-yellow were therefore significant.

In percentage by weight of the various colors reddish-yellow, yellowish-red, yellow, and red occurred in decreasing frequency.

DISCUSSION

A general summary of the results previously presented is given in Table 4. In this table preferences as listed are based upon significant differences only. High seed weight and germination and low percentages of hard seeds have been assumed to be desirable. In the present studies only seedling vigor in germination has been recorded. The relation of seed color to the later development of the plant is to a considerable extent problematical.

TABLE 4.—*Summary indicating color preferences in clovers for the several respects studied.*

Character	Preference		
	Red	Alsike	White
Weight in grams per 100 seeds	Purple or yellowish purple	Black	Red
Blotter germination, total	Yellow, purplish yellow, or yellowish purple	Greenish-black, black, or blackish green	Yellow
Hard seeds	Yellow, purplish yellow, yellowish purple	Greenish-black, black, or blackish green	Yellow or reddish yellow
Soil germination	No preference	Greenish-black, black, or green	Yellow

Williams (5) has pointed out that seed color in red clover may be influenced by genetic factors and environment. Stapledon, cited by Williams, noted differences to exist in proportions of the various colors in red clover seed lots from different strains and several countries. Reports as to what extent similar conditions exist in white and alsike clovers have not been seen. In recognition of these facts study of numerous samples from many sections would be desirable before inclusive generalizations are made.

SUMMARY

1. Five lots each of red, alsike, and white clover seed were separated individually into four color classes and data obtained on average seed weight, percentage in the sample, germination on blotters and in soil, and hard seeds.

2. Purple and yellowish purple seeds averaged higher in weight than other colors in red clover. Darker-colored seeds were also heavier in alsike and white clovers.

3. Intermediate seed colors were generally most numerous in all clovers studied. Dark colors were frequent in alsike and less so in red and white clovers.

4. In total germination of red clover on blotters, yellow or yellowish seeds were superior. Total germination favored darker colors in alsike clover and yellow in white clover.

5. Hard seeds were most frequent in purple and purplish groups in red clover, in green and blackish-green in alsike clover, and in red and yellowish-red in white clover.

6. Germination in soil was highest in the darker colors in alsike clover and yellow was superior in white clover. Color differences in soil germination of red clover were very slight.

7. Average number of seeds per pound calculated for the samples studied were red clover, 293,600; alsike clover, 677,000; and white clover, 836,100.

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REGISTRATION OF IMPROVED WHEAT VARIETIES, XIII[1]

J. ALLEN CLARK[2]

TWELVE previous reports present the registration of 58 improved varieties of wheat. In 1938, three varieties were registered.[3] Four varieties have been approved for registration in 1939, as follows:

Varietal name	Reg. No.
Wabash	324
Renown	325
Coronation	326
Regent	327

WABASH, REG. NO. 324

Wabash (C. I. 11384)[4] was developed by selection in cooperative experiments of the Department of Botany, Purdue University Agricultural Experiment Station, Lafayette, Ind., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. The original head selection, C. I. 5308, was made from Fultz at Columbia, Mo., in 1913. This original head proved to be a natural hybrid, as it segregated for a number of characters, including glume color and disease resistance. Wabash is the result of a series of selections of which the final selection was made at the Purdue University Agricultural Experiment Station in 1924. It is superior to standard soft red winter wheats in yield, winter hardiness, and resistance to leaf rust and mosaic. Wabash is tall, with white mid-strong straw, awnleted spikes, white glabrous glumes, and soft red kernels. It has been under test for 8 years at Lafayette, Ind., and, in the fall of 1938, was approved for commercial distribution both by the Purdue University Agricultural Experiment Station and the Illinois Agricultural Experiment Station. The Purdue University Agricultural Experiment Station applied for its registration.

Yields and other data upon which registration was based are shown in Table 1.[5]

RENOWN, REG. NO. 325

Renown (C. A. N. 1856; R. L. 716; C. I. 11635) was developed from a cross between H-44 and Reward made in 1926 at the Dominion Rust Research Laboratory, Manitoba Agricultural College, Winni-

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 7, 1939.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, member of the 1939 Committee on Varietal Standardization and Registration charged with the registration of wheat varieties.

[3]CLARK, J. ALLEN. Registration of improved wheat varieties, XII. Jour. Amer. Soc. Agron., 30:1037–1042. 1938.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases.

[5]For further information on Wabash wheat, see Report of Progress, 1915–1934, Soils and Crops Experiment Farm, Purdue University Agricultural Experiment Station. 1935.

peg, Manitoba. Selection R. L. 716 was made in 1927 and this strain was tested for yield and quality at an increasing number of stations in Canada from 1929 to 1937, when it was first distributed for commercial growing. The variety was reselected in 1932 and a single line strain (R. L. 716.6, C. I. 11947) was increased and distributed in 1939, in which year it was made one of the "uniform varieties" grown in plat experiments at all cooperating spring wheat stations in the United States. Renown was developed by the Cereal Division, Dominion Experimental Farms System, and this Division applied for its registration.

TABLE 1.—*Comparative yields and leaf rust resistance of Wabash and other standard winter wheats at Lafayette, Ind., 1930–38.*

Variety	Yield in bushels per acre									Leaf rust average†
	1930	1931	1932	1933	1934	1935	1937*	1938	Average	
Wabash (new)	30.1	45.3	28.6	32.6	37.4	40.6	23.6	30.5	33.6	5.9
"Michigan Amber"‡	29.1	41.9	28.5	30.8	38.6	30.1	19.6	29.2	31.0	73.8
Purkof	31.4	46.0	26.5	24.9	40.1	32.2	8.1	27.4	29.6	31.3
Fultz	28.9	38.4	28.5	28.6	36.7	28.6	18.7	23.8	29.0	——

*Soil infested with wheat mosaic.
†Average 1931 to 1938.
‡Synonym of Red May.

The superior characters reported for Renown are high yield, medium early maturity, and resistance to stem rust, leaf rust, and bunt. It has awnleted spikes, white glabrous glumes, short dark red kernels, and red coleoptiles.

Table 2 presents the yields reported upon which registration was based. The application, however, was accompanied by large annual mimeographed reports giving the individual station yields, milling and baking data, etc.

TABLE 2.—*Comparative yields of Renown and standard hard red spring wheats grown in nursery (six replications) experiments at various stations in western Canada.*

Variety	1934	1935	1936	1937	1938	Average	Percentage of Marquis
Number of stations	11	13	12	14	15		
Renown (new).........	28.8	29.3	17.2	23.2	28.6	25.4	121.0
Ceres (standard).......	31.6	21.2	18.8	21.5	22.5	23.1	110.0
Marquis (standard)....	28.5	19.4	17.4	19.9	19.8	21.0	100.0

CORONATION, REG. NO. 326

Coronation (C. A. N. 1915; R. L. 729; C. I. 11475) was developed from a cross between Pentad (red durum) and Marquis made in 1925 at the Dominion Rust Research Laboratory, Winnipeg, Canada. The

selection resulting in Coronation was made in 1927 and the wheat was tested for 9 years or until 1937, when it was distributed. The superior characters reported for Coronation are high yield and resistance to stem rust, leaf rust, and bunt. Unlike the other two new Canadian wheats, Renown and Regent, which obtained their rust resistance from H-44, a sister strain to Hope, the Coronation resistance came originally from Pentad durum and is the result of a species hybrid. Coronation is awned and has white glabrous glumes and dark red kernels. Milling and baking data place Coronation in a different quality category from that in which Renown and Regent are placed. This difference is recognized in grading, and the variety is recommended for distribution in a more eastern area.

Table 3 presents the reported yields upon which registration was based.

TABLE 3.—*Comparative yields of Coronation and standard hard red spring wheats grown in nursery (six replications) experiments at various stations in western Canada.*

Variety	1934	1935	1936	1937	1938	Average	Percentage of Marquis
Number of stations	1	1	12	14	1		
Coronation (new)......	42.3	17.0	19.8	23.5	26.4	25.8	179.1
Ceres (standard).......	31.0	3.3	18.8	21.5	8.8	16.7	116.0
Marquis (standard)....	24.1	3.3	17.4	19.9	7.5	14.4	100.0

REGENT, REG. NO. 327

Regent (C. A. N. 1902; R. L. 975.1; C. I. 11869) was developed from a cross between H-44 and Reward made in 1926 at the Dominion Rust Research Laboratory, Winnipeg, Canada. Like Renown and Coronation, it is a product of the Dominion Experimental Farms System. The superior characters reported for Regent are high yield, medium early maturity, and resistance to stem rust, leaf rust, and bunt. It has awnleted spikes, white glabrous glumes, and mid-long red kernels. Strain R. L. 975 was first selected in 1928, reselected in 1932, tested from 1934 to 1938, and distributed in the spring of 1939. The yields reported upon which registration was based are given in Table 4.

TABLE 4.—*Comparative yields of Regent and standard hard red spring wheats grown in nursery (six replications) experiments at various stations in western Canada.*

Variety	1934	1935	1936	1937	1938	Average	Percentage of Marquis
Number of stations.....	1	1	12	14	15		
Regent (new)..........	40.6	20.8	17.3	24.9	30.8	26.9	159.2
Ceres (standard).......	31.0	3.3	18.8	21.5	22.5	19.4	114.8
Marquis (standard)....	24.1	3.3	17.4	19.9	19.8	16.9	100.0

For further information on Renown, Coronation, and Regent wheats see Handbook of Canadian Spring Wheat Varieties, by L. H. Newman, J. G. C. Fraser, and A. G. O. Whiteside. Canada Dept. Agr. Pub. 538, 54 pages. March, 1939.

REGISTRATION OF VARIETIES AND STRAINS OF OATS, IX[1]

T. R. STANTON[2]

THE eighth annual report (6)[3] on the registration of improved varieties of oats was published in December, 1938. During 1939 five varieties were submitted and approved for registration. They are as follows:

Group and Varietal Name	Reg. No.
Early yellow:	
Boone	87
Hancock	88
Early white:	
Marion	89
Midseason red:	
Fulwin	90
Tennex	91

Information on the origin, development, description, performance, and probable agronomic value of these new varieties on which approval for registration is based, is summarized in the paragraphs below.

BOONE, REG. NO. 87

Boone (C. I. 3305)[4] was originated from a cross (No. XS1098) between Victoria and Richland, made by the writer in the greenhouse at the Arlington Experiment Farm, Arlington, Va., in 1930. This cross was made to introduce the crown rust and smut resistance of the Victoria variety into Richland type oats. Information on the growing and handling of this cross has been published (5, 7, 8).

Boone was developed cooperatively by the Iowa Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Those besides the writer who had a part in the development of Boone are H. C. Murphy, F. A. Coffman, L. C. Burnett, and H. B. Humphrey. The group of selections from which Boone was originated also was grown in certain years at the Aberdeen Substation, Aberdeen, Idaho, in the greenhouse at the Arlington Experiment Farm, Arlington, Va., and at the Brooklyn Botanic Garden, Brooklyn, N. Y., under the supervision of Harland Stevens, John W. Taylor, and George M. Reed, respectively. Application for the registration of Boone was made by the writer at the request of the Seed Distribution Committee of the Iowa Agricultural Experiment Station.

[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 9, 1939.

[2]Senior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, member of the 1939 Committee on Varietal Standardization and Registration charged with the registration of oat varieties.

[3]Reference by number is to "Literature Cited", p. 82.

[4]C. I. refers to accession number of the Division of Cereal Crops and Diseases, formerly Office of Cereal Investigations.

Boone is classified as an early yellow common oat, with short, stiff straw like that of the Richland parent and plump kernels with few awns. Its superior characters are early maturity, high yield and quality, and high resistance to nearly all physiologic races of stem rust, crown rust, and the smuts of oats. Boone was tested in a 15-foot row in 1935 and in replicated plats from 1936 to 1939 in the cooperative experiments at Ames and Kanawha, Iowa. The data obtained are shown in Table 1.

For data on the yield of Boone at experiment stations in other States, and for further information on its high resistance to disease, the reader is referred to published articles (5, 7, 8) and to mimeographed reports.[5]

Boone will be distributed to farmers of Iowa for growing in 1940.

HANCOCK, REG. NO. 88

Hancock (C. I. 3346) was originated from a cross (No. X2871) between Markton and Rainbow oats made in the greenhouse at the Arlington Experiment Farm by F. A. Coffman in 1928. The F_1 plants were grown at the Aberdeen Substation in 1928, the F_2 generation was grown in the greenhouse at Arlington Farm in the winter of 1928–1929, and the F_3 to F_5 generations were grown en masse at Ames, Iowa, from 1929 to 1931. Information on the group of selections from which Hancock was derived has been published (1).

Hancock was developed cooperatively by the Iowa Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, at Ames, Iowa. Those having a part in the breeding of Hancock, besides F. A. Coffman, are H. C. Murphy, T. R. Stanton, L. C. Burnett, and H. B. Humphrey. The group of selections giving rise to Hancock also was grown in certain years at the Aberdeen Substation under the supervision of L. L. Davis and Harland Stevens, and in the greenhouse at Arlington Farm under the supervision of John W. Taylor. Application for the registration of Hancock was made by F. A. Coffman at the suggestion of the Seed Distribution Committee of the Iowa Agricultural Experiment Station.

Hancock is an early common yellow to yellowish white oat with tall very stiff culms and plump kernels with relatively few awns. The superior characters of Hancock are early maturity, good quality, exceptionally stiff straw that resists lodging, and resistance to stem rust and to most physiologic races of loose and covered smut. Hancock is primarily a special purpose variety for growing with and combining over newly-sown stands of sweet clover. Hancock was tested in repli-

[5]BURNETT, L. C. Information from experiments in progress, small grains summary. Iowa Agr. Exp. Sta. Leaflet F. C. 10. Jan. 1939. [Mimeographed.]

COFFMAN, F. A. Results from the cooperative, coordinated oat-breeding nurseries for 1938 and the uniform winter hardiness nurseries for 1938–39, together with average for previous years. U. S. Dept. Agr., Bur. Plant Indus., Div. Cereal Crops and Diseases [Unnumb. Pub.] 100 pp. July 15, 1939. [Mimeographed.]

STANTON, T. R. Disease-resistant oat varieties. U. S. Dept. Agr., Ext. Path. Serial No. 39, 70–71. August 1939. [Mimeographed.]

cated plats at Ames and Kanawha, Iowa from 1935 to 1939. The yields of Hancock, compared with those of Iogold and Richland, standard varieties in Iowa, are shown in Table 2.

For yields of Hancock and Marion in other states and for additional information on its disease resistance, see Coffman, *et al.* (1), and also special mimeographed reports.[6] Hancock was increased in 1939 for distribution to farmers of northern Iowa in 1940.

MARION, REG. NO. 89

Marion (C. I. 3247), like Hancock, was originated from the Markton-Rainbow cross (No. X2871) made by F. A. Coffman at Arlington Farm in 1928. The selection, testing, and disease resistance of Marion have been reported (1). Marion is a product of the cooperative oat improvement program of the Iowa Agricultural Experiment Station and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Among those having a part in the breeding of Marion besides F. A. Coffman are H. C. Murphy, T. R. Stanton, L. C. Burnett, and H. B. Humphrey. The group of selections from which Marion was originated also was grown in one or more years at the Aberdeen Substation under the supervision of L. L. Davis and Harland Stevens, and at the Arlington Farm under the supervision of John W. Taylor. Application for the registration of Marion was made by F. A. Coffman at the suggestion of the Seed Distribution Committee of the Iowa Agricultural Experiment Station.

Marion is an early to midseason yellowish white to white common oat with midtall to tall plants, a stiff straw, and plump kernels with relatively few awns. Marion is a white oat obtained by crossing two yellow varieties. The superior characters of Marion are early maturity, high yield, and high test weight, with kernels of the best type for milling and for feed. It also has stiff straw and resistance to stem rust and smut, as well as resistance to certain races of crown rust. Marion has been grown in replicated plats at Ames and Kanawha, Iowa from 1935 to 1939. The yields of Marion and of Iogold and Richland, standard Iowa varieties, are given in Table 2.

FULWIN, REG. NO. 90

Fulwin (C. I. 3168 and Tenn. No. 1945) was originated as a reselection from Fulghum (winter type, sel. 699–2011 and C. I. 2499) by Newman I. Hancock at the Tennessee Agricultural Experiment Station, Knoxville, Tenn. Mr. Hancock submitted the following notes on origin with the applications for the registration of Fulwin and the sister variety, Tennex, discussed later:

"*History.*—In the crop year 1929–30 it was observed that Fulghum, sel. 699–2011, was very winter hardy, but that it contained many off-type plants. A thousand head or panicle selections were made and sown in rows 39 inches long in the fall of 1930. Around two thousand panicle selections again were made during the harvest of 1931 and sown the following fall. * * *

[6]See footnote 5.

TABLE 1.—*Yields of Boone, Iogold, and Richland (Iowa 105) oats grown at Ames and Kanawha, Iowa, 1935–39.*

Variety	Acre yield, bushels											
	1935, Ames	1936		1937		1938		1939		Averages		
		Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames and Kanawha*
Boone	89.0	76.0	85.0	96.8	102.3	70.6	70.0	44.7	79.9	75.4	84.3	79.4
Iogold	60.5	78.6	70.7	75.2	74.7	37.8	27.8	46.2	69.5	59.7	60.7	60.1
Richland	58.1	67.0	78.3	77.2	78.9†	41.9	37.2	44.7	65.4	57.8	65.0	61.0

*Average of 9 station years.
†Estimated yield.

TABLE 2.—*Yields of Hancock, Marion, Iogold, and Richland (Iowa 105) oats at Ames and Kanawha, Iowa, 1935–39.*

Variety	Acre yield, bushels												
	1935		1936		1937		1938		1939		Averages		
	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames	Kanawha	Ames and Kanawha*
Hancock	53.5	62.5	66.0	79.3	93.8	79.3	48.7	65.4	45.3	68.9	61.5	71.1	66.3
Marion	49.5	90.4	76.6	92.7	101.6	97.3	46.6	70.9	54.1	79.9	65.7	86.2	76.0
Iogold	46.9	59.9	70.3	62.1	67.2	74.5	37.8	27.8	46.2	69.5	53.7	58.8	56.2
Richland	62.0	62.1	55.0	67.0	69.0	79.7†	41.9	37.2	44.7	65.4	54.5	62.3	58.4†

*Average of 10 station years.
†Estimated yield.

"Seed was saved from the best strains of 1931–32 which were grown in rod rows. * * * The best strains or rows were again saved and * * * were sown in rod rows * * * the third crop year. In the following crop years larger plats were used, * * * Tenn. Nos. 1945 and 1884 originating from the 945th and 884th panicle rows of 1930–31, respectively.

"Fulghum sel. 699–2011 was originated by T. R. Stanton, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. Agriculture, from whom it was received by the Tennessee station in the fall of 1929."

For further detailed information on the origin of sel. 699–2011, see Stanton (4). The following description of Fulwin was submitted by Mr. Hancock with the application for registration:

"*Description.*—Culms slightly hairy at the nodes, midsized, tendency to lodge if planted too thick; 90 to 120 cm long. Sheaths light green, slightly hairy or glabrous. Culm leaves midwide, margins slightly hairy at basal portions. Peduncles slender, straight, ascending, well exserted, 25 to 35 cm long. Panicles erect, equilateral, very long, open and spreading. Rachises with 5 to 7 nodes, branches short to long, ascending, scabrous, a whorl of 2 to 7 branches at each node. Spikelets few to numerous, 2-flowered, sometimes 3-flowered; usually separating from their pedicels by fracture; kernels slender to mid-plump. Glumes 20 to 25 mm long, 6 to 8 mm wide, 9- to 11-veined, light green before maturity. Lower lemmas 16 to 18 mm long, reddish yellow at maturity; basal hairs few or absent; awns few to common, straight, scabrous. Basal hairs few or absent at callus. Upper lemmas 12 to 15 mm long, reddish yellow at maturity. Rachilla segment 2 to 2½ mm long, nearly glabrous; articulates with upper grain in most instances."

The superior characters of Fulwin are winter hardiness, high yield, vigorous, tall plants, and suitability for late seeding after corn is harvested in Tennessee. Fulwin has been tested in replicated nursery rows and field plats at Knoxville. The yields of Fulwin and of standard and other varieties are given in Table 3.

TABLE 3.—*Yields of Fulwin, Tennex, and other varieties of winter oats grown at Knoxville, Tenn., 1934–38.*

Variety	Acre yield, bushels						
	1934	1935	1936*	1937	1938	Averages	
						1934–38	1935–38
Fulwin	51.2	43.1	19.1	87.0	46.0	49.3	48.8
Tennex	48.6	42.2	16.5	86.0	48.5	48.4	48.3
Winter Turf	33.8	22.6	2.8	54.8	36.1	30.0	29.1
Fulghum (sel. 699–2011)	39.6	37.1	7.4	61.5	—	—	36.4†
Lee	—	28.8	6.3	75.1	48.3	—	39.6
Coker 32–1	—	24.7	2.5	62.9	41.7	—	33.0

*Low yields due to a heavy infestation of plant lice in the fall, followed by severe injury by freezing to the weakened seedlings that remained.
†Average 1934–37.

TENNEX, REG. NO. 91

Tennex[7] (C. I. No. 3169 and Tenn. No. 1884) is a sister strain of Fulwin having been originated from Fulghum (winter type sel. 699–2011 and C. I. 2499) by Newman I. Hancock at the Tennessee Agricultural Experiment Station, Knoxville, Tenn., who also made application for its registration.

Tennex is similar to Fulwin in nearly all plant characters. It differs from Fulwin only in having darker green leaves in the seedling stage and in flowering a week to 10 days earlier. The grains also are slightly smaller and have stronger awns, some of which are twisted and subgeniculate.

The superior characters of Tennex are winter hardiness, high yield, and early maturity. It ripens from two to three weeks earlier than Winter Turf and 10 days earlier than Lee at Knoxville. Like Fulwin, it also is more satisfactory for late seeding after corn than these older varieties. Tennex has been tested in replicated nursery rows and field plats at Knoxville. Yields of Tennex and of standard and other varieties of oats at Knoxville are given in Table 3.

Yield data on Fulwin and Tennex and other varieties at Knoxville, Jackson, and Columbia, Tenn., are shown in Table 4.

TABLE 4.—*Yields of Fulwin, Tennex, and four other varieties of winter oats grown from early and late seeding at Knoxville, Jackson, and Columbia, Tenn.*

Variety	Acre yield, bushels					
	Knoxville			Jackson		Columbia
	Average 1934 to 1938, early seeding	1938		Average 1937 and 1938, early seeding	1938, early seeding	1938, late seeding
		Early seeding	Late seeding			
Fulwin	49.3	46.0	38.3	79.2	75.8	25.0
Tennex	48.4	48.5	40.7	80.0	81.7	34.4
Fulghum (sel. 699–2011)	36.4*	—	—	—	—	—
Winter Turf	30.0	36.1	—	45.4	43.3	17.2
Lee	39.6†	48.3	11.4	61.7‡	61.7	—
Coker 32–1	33.0†	41.7	34.5	63.8	57.5	13.3

*Four-year average, 1934–37.
†Four-year average, 1935–38.
‡Yield for 1938 only.

Data on relative winter hardiness of Fulwin, Tennex, and on other varieties, submitted by Mr. Hancock, are shown in Table 5.

[7]The official spelling has been changed recently by the Tennessee Agricultural Experiment Station from "Tenex" to "Tennex."

TABLE 5.—*Average hardiness indexes of Fulwin, Tennex, and four other varieties of winter oats when tested in cold chambers at the Iowa Agricultural Experiment Station, Ames,* 1933–34 and 1934–35, and in nurseries at 28 experiment stations in the United States in the crop years 1936–37 and 1937–38.*†

Variety	Average survival							
	In cold chambers				In uniform nurseries			
	1933–34		1934–35		1936–37		1937–38	
	%	Rank‡	%	Rank‡	%	Rank§	%	Rank¶
Fulwin	75.0	6	73.1	3	92.8	1	76.1	1
Tennex	74.2	7	68.3	7	91.9	2	75.6	2
Hairy Culberson	—	—	68.2	8	90.3	4	71.3	7
Winter Turf	—	—	60.0	11	86.6	12	67.6	14
Fulghum (sel. 699–2011)	—	—	53.1	20	88.4	9	71.4	6
Coker 32–1	—	—	57.8	13	87.9	10	70.1	11

*Results of cooperative experiments conducted by H. C. Murphy of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Iowa Agricultural Experiment Station. For more complete data see Murphy (3).

†Coffman, F. A. Results from the cooperative, coordinated oat-breeding nurseries for 1937 and the uniform winter-hardiness nurseries for 1937–38, together with average for previous years. U. S. Dept. Agr., Bur. Plant Indus., Div. Cereal Crops and Diseases [Unnumb. Pub.] 108 pp. May 28, 1938. [Mimeographed.]

‡Data from 35 varieties and selections in 1933–34 and in 1934–35.

§Data from 28 varieties.

¶Data from 30 varieties.

For further information regarding the development of Fulwin and Tennex oats, see the forty-ninth annual report of the Tennessee Agricultural Experiment Station (9, page 10), and special articles by Elliott (2) and Hancock.[8]

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[8]HANCOCK. N. I. New Tennessee winter oats. Tenn. Agr. Exp. Sta. Circ. of Inform. 47, 2 pp. July 22, 1939. [Mimeographed.]

REGISTRATION OF IMPROVED COTTON VARIETIES, II[1]

H. B. Brown[2]

THE first report on the registration of improved cotton varieties was published in December 1936.[3] No varieties were registered in 1937 or 1938. An application for registration was received in 1938, but it was not submitted and approved until 1939. This variety was named Texacala and given Registration No. 35. Below is a brief description of the variety.

TEXACALA, REG. NO. 35

Texacala, formerly known as Rogers Acala 111, originated from a plant selection made near Navasota, Texas, in 1924 by J. H. McDonald, who is plant breeder for the John D. Rogers Seed Company, Navasota, Texas. The parent stock of this variety was secured from D. A. Saunders in 1921. Saunders assisted in the acclimatization of this cotton after its importation from Mexico some years previously. Following the selection, the strain was subjected to self-fertilization, roguing, and re-selection. This resulted in a strain of very uniform type. It is characterized by excellent productivity, especially under slightly arid conditions, and the very desirable combination of good lint percentage and good staple length. It is grown extensively in Texas and has been introduced in Mexico, Greece, and Ecuador.

Under good growing conditions, the plants attain a height of 3 to 5 feet; vegetative branches are few; fruiting branches are long on the lower part of the plant but short on the upper part, thus producing a cone-shaped plant; leaves medium sized, dark green; bolls short-pointed, snub-nosed type—66 to 78 per pound; staple length, 1/32 to 1⅛ inches; percentage lint 34 to 38; seeds medium size, 3,600 per pound; lint index 7.6 to 8.2; somewhat earlier than other of the Texas big boll varieties.

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[1]Registered under a cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication November 30, 1939.

[2]Agronomist, Louisiana Agricultural Experiment Station, University, Louisiana, and a member of the 1939 Committee on Varietal Standardization and Registration, charged with the registration of cotton varieties.

[3]Brown, H. B. Registration of improved cotton varieties, I. Jour. Amer. Soc. Agron., 28:1019–1020. 1936.

BARLEY VARIETIES REGISTERED, V[1]

H. K. HAYES[2]

ONE variety of barley was approved for registration in 1937[3] making seven varieties registered previous to this report. One variety was approved for registration in 1939.

REX, REG. NO. 8

Rex is a lax, six-rowed, hulled, smooth-awned barley with high yielding ability, early maturity, and high bushel weight produced at the University of Saskatchewan, Canada, by Dr. J. B. Harrington from a cross of Velvet with Hannchen. It was first distributed for sowing in 1939.

Comparative yields of Rex and four other varieties are given in Table 1.

TABLE 1.—*Comparative yields on summer fallow at Saskatoon, Sask., in rod-row plots with six replications randomized.*

Variety	Average yield in bushels per acre					
	1934	1935	1936	1937	1938	Average
Rex, Sask. 1761	48.4	41.2	23.5	2.6	29.1	29.0
Hannchem, Sask. 229	44.8	40.7	20.4	8.9	24.5	27.9
Trebi, Sask. 101	46.6	51.2	18.7	5.4	17.5	27.9
Regal, Sask. 1865	48.2	41.7	14.1	3.1	20.5	25.5
O. A. C. 21, Sask. 228	39.0	26.6	10.2	1.9	15.0	18.5

TABLE 2.—*Agronomic characters of Rex and four other varieties on summer fallow 1934–38, inclusive, Saskatoon, Sask.*

Variety	Height of plant, cms	Straw strength, %	Days seeding to ripe	Weight in lbs. per bu.	1,000 kernel weight, grams
Rex	65	95	80	52.3	34.0
Hannchen	60	91	83	52.9	30.3
Trebi	57	92	79	44.5	34.8
Regal	66	98	82	48.6	28.8
O.A.C. 21	63	91	81	45.3	26.0

Comparison of agronomic characters of Rex and other varieties are given in Table 2. Rex excels Hannchen in length and strength of straw, matures earlier, and is equal to Hannchen in yield and bushel weight of grain.

[1]Registered under the cooperative agreement between the Bureau of Plant Industry, U. S. Dept. of Agriculture, and the American Society of Agronomy. Received for publication December 4, 1939.

[2]Chief, Division of Agronomy and Plant Genetics, Department of Agriculture, University of Minnesota, St. Paul, Minn. Member of committee on Varietal Standardization and Registration of the Society charged with the registration of barley varieties.

[3]HAYES, H. K. Barley varieties registered, IV. Jour. Amer. Soc. Agron., 29: 1032–1033. 1937.

BOOK REVIEWS

ECOLOGY OF FIELD CROPS (ECOLOGIE AGRICOLE)

By J. S. Papadakis. Edited by Jules Duculot, Gembloux, Belgium, in Bibliotheque Agronomie Belgae. Paris: Librairie Agricole de la Maison Rustique. XV+312 pages, illus. Paper bound. 1938.

THE word "agricultuer" is used here in its literal meaning of cultivation of field crops. Although most farm products which would be included under agronomy are considered, major attention is given the small cereals. After a discussion of general principles, the developmental periods of plants are considered in relation to long and short periods of flowering, temperature, and length of day. A classification of crop plants from the point of view of developmental periods is given.

Various ecological factors are treated in considerable detail in about one-fourth of the book. These factors include water relations, snow, climate, phytosociology, cultivation, and soil in relation to climate, illustrated by a map of the world showing the distribution of 12 kinds of climatic soils and smaller maps of these soils in Europe and the United States.

In the chapter "Ecology of the Small Grains" is an extended table showing dates of earing observed by the author in tests with numerous varieties of wheat, rye, barley, and oats planted at different times in various parts of Greece. Several chapters are devoted to the ecology of a number of non-cereal crops.

About one-fifth of the volume is devoted to the chapter "Ecological Classification of Climate". The climates in which field crops are grown have been divided into 43 types grouped under five belts. Each type is discussed briefly as regards temperature, precipitation, and influence on various crops. Data regarding 92 stations throughout the world are given in tables and in graphs. The latter show monthly mean temperature, rainfall, and soil moisture in excess or below plant requirements. A map of the world shows the distribution of the zones and types of climates.

The text and tables contain information on soil types accompanying climatic types, climax vegetation, and relative influence of climate on the development of cereals and other crops. In one chapter, the methods of ecological research are considered, including a short discussion of statistical methods and plat technic. The final chapter is devoted to crop improvement through genetics and adaptation of plants to suitable environments. The citation of literature includes 167 entries many of which are by foreign authors.

The book is well written in French that is not difficult to translate. The author has brought together a wealth of information, but his analysis of the subject matter and his contributions from his experiments constitute a valuable part of the book. The numerous maps and diagrams enhance the value of the work. While soil and climate have been treated from a world-wide viewpoint, special consideration of the various crops have been restricted largely to the United States

and Europe. The book should prove an excellent text for those interested in the geography and ecology of crop plants. (F. Z. H.)

SOIL CONSERVATION

By Hugh Hammond Bennett. New York: McGraw-Hill Book Co., Inc. XVII+993 pages, illus. 1939. $6.

FOR more than 30 years Hugh Hammond Bennett has been a persistent champion of soil conservation. Here at long last is a book from his pen sufficiently broad in scope to represent in technical literature the personal achievements of the author. But the book is in no sense an autobiography. Against a background of the history of soil destruction in the United States and throughout the world, it presents a wealth of factual information that gives perspective to the whole involved problem of land use, and brings into sharp focus the urgent necessity of a national program of soil conservation to counteract the rapid depletion of our soil resource.

"Soil Conservation" discusses the rates at which soils are being destroyed by misuse, and emphasizes the relationship of erosion and water wastage to flood control, sedimentation, agricultural impoverishment, and the inevitable subsequent sociological and economic problems. Measures for soil defense and reclamation are presented, together with means for putting a national soil conservation program into effective operation. For many, the chapter on a national program of soil conservation will prove to be the most important one in the text.

As climate and type of agriculture vary from one section of the country to another, the erosion problem is also modified. Perhaps no one is more familiar with the local and regional aspects of the problem than is Hugh Bennett. In "Soil Conservation", one finds descriptions of specific problem areas, within the confines of which there are characteristic conditions of soil erosion and land use. This geographic analysis of the national problem should direct the attention of readers to the necessity of specific knowledge in the application of control or regulatory measures.

To detail further the contents of the book is useless. The book has an encyclopaedic quality that is impossible to characterize by a mere listing of contents. Over a period of years many workers have contributed to the literature on soil erosion by wind and water. These prior writings have been drawn upon to furnish illustrative data to show the extent of the erosion problem, and the adequacy of available and practical methods of control. If, as the author suggests, a limitation of space has necessitated the omission of much material pertinent to a complete treatise, the reviewer can add only that selection has been comprehensive enough to develop completely the major thesis of the science and practice of soil and water conservation.

The book is attractive in appearance, on good paper, profusely and well illustrated. (C. S. S.)

AGRONOMIC AFFAIRS

A NEW EDITORIAL BOARD FOR THE JOURNAL

COMPLYING with the recommendations of the Editorial Advisory Committee made to the Society at the annual meeting in New Orleans, La., November 23, 1939, and adopted by unanimous vote, the Executive Committee elected J. D. Luckett, Editor; Dr. Ralph J. Garber, Associate Editor in Crops; and Professor Emil Truog, Associate Editor in Soils, for the year 1939–40.

As heretofore, all papers to be submitted for publication in the JOURNAL should be directed to the Editor at the New York State Experiment Station at Geneva. The Editor will in turn refer all crops papers to the Associate Editor in Crops and all soils papers to the Associate Editor in Soils. Each of the Associate Editors has named a corps of Consulting Editors which will serve as a review board for papers in their respective fields. These two groups are as follows:

Consulting Crops Editors, Dr. H. K. Hayes, University of Minnesota; Dr. M. T. Jenkins, U. S. Dept. of Agriculture; Dr. R. D. Lewis, Ohio State University; Dr. L. F. Graber, University of Wisconsin; and Dr. Ide P. Trotter, Texas A. & M. College.

Consulting Soils Editors: Dr. G. B. Bodman, University of California; Dr. I. L. Baldwin, University of Wisconsin; Dr. W. H. Pierre, Iowa State College; and Dr. L. D. Baver, Ohio State University.

This new Editorial Board, which replaces the Editorial Advisory Committee, has already begun to function and is confidently expected to strengthen materially the editorial supervision of the JOURNAL.

STUDENT SECTION ESSAY CONTEST FOR 1940

STUDENTS presenting the best papers in the Student Section essay contest sponsored by the Society will receive awards as follows: The first three winners receive expense money to enable them to attend the International Grain and Hay Show in Chicago. The total allotment for the three will not exceed $150.00. The amounts granted may vary with the distance the winners are from Chicago. For example, if a Wisconsin student won first and an Oregon student second, it would be desirable to grant a larger amount to the Oregon student, as his expenses would be greater. The committee reserves the right to adjust this as conditions warrant. In addition, the three high men will receive appropriate medals and a year's subscription to the JOURNAL of the American Society of Agronomy.

The winners of the fourth, fifth, sixth, and seventh places will receive cash awards of $20, $15, $10, and $5, respectively.

All essays must be prepared by undergraduate students. Students graduating during the course of the 1939–40 school year or those graduating during the summer school of 1940 are eligible, providing their papers are submitted before graduation. A certification of

eligibility to qualify as an undergraduate, signed by the dean of the college, must accompany each paper.

Papers should be typed, double spaced and not less than 3,000 or more than 3,500 words in length. *Abstracts of not more than 500 words must accompany each paper.* Abstracts should be prepared carefully as it is planned to publish the best. Failure to submit an abstract will disqualify the paper.

The title for the essay shall be "Causes of Run-down Pastures and Methods of Their Improvement". The subject may be treated for any section or all sections of the United States and from any angle.

All papers are to be submitted in duplicate and if it is desired that the essay be returned, postage should be enclosed.

The committee suggests, that where several papers are entered from a given institution, the local representatives of the Society review the essays and submit only the best articles. This will save work for the committee and reduce mailing expenses. Usually not more than five papers should be submitted from one institution for final review by the committee. The winners of the contest will be announced at the meeting of the American Society of Agronomy in Chicago in November, 1940, and the results published in the December 1940 issue of the JOURNAL.

Essays must be in the hands of the chairman of the committee, H. K. Wilson, University Farm, St. Paul, Minnesota, not later than August 1, 1940.

EIGHTH AMERICAN SCIENTIFIC CONGRESS

THE eighth American Scientific Congress will be held in Washington, D. C., May 10 to 18, 1940, under the auspices of the United States government. Invitations have been extended to governments members of the Pan American Union to participate in the Congress and scientific institutions and organizations are also invited to send representatives.

The Congress will be divided into the following sections: Anthropological Sciences, Biological Sciences, Geological Sciences, Agriculture and Conservation, Public Health and Medicine, Physical and Chemical Sciences, Statistics, History and Geography, International Law and Public Law and Jurisprudence, Economics and Sociology, and Education. Chairmen of the respective sections will be named at an early date.

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THE SOCIAL AND ECONOMIC PROBLEMS OF SOUTHERN AGRICULTURE[1]

W. C. LASSETTER[2]

WE are happy to welcome the American Society of Agronomy to the South where we have social, economic and agronomic problems. We are highly honored by your presence.

Before starting it might be well to define the area to which we shall refer as the South. For convenience we are letting this area begin with Virginia and West Virginia to the northeast, Kentucky to the North, and extend across all of the states of the southeast and including Arkansas, Oklahoma and Texas in the southwest. This forms an area comprised of fourteen states more commonly known as the South.

To understand better some of the social and economic problems of the South you may need to know more about the South itself. It is a country of sharp contrasts. In soils it has the blackest and the whitest. In population the whitest and the blackest. And in each case all gradations in between. In the great Mississippi Delta area we have gathered some of the richest of all soils contributed by the farms of Pennsylvania and Ohio, Montana and the Dakotas, and the great basin in between. You may be interested to know your Northern soils concentrated in our Mississippi Delta grow the whitest and finest of cotton and the sweetest of sugar cane. When we thought our deltas were rich enough we built levies so that the less rich land you are now sending down is being dumped into the Gulf of Mexico. While these vast delta areas have been busy receiving the best soils the country afforded, scarred hillsides in other parts of the South have been equally as busy giving up the best they had.

Farm lands over certain vast areas in the South lie in large, level or rolling fields in such condition that they can be worked with the most modern of farm machinery. In sharp contrast we have other vast areas where fields are small and slopes so steep that their cultivation is accomplished only with greatest difficulty. In size, farms vary from the proverbial one-horse farm of the old cotton belt, an

[1]Presented on the general program of the thirty-second annual meeting of the Society held in New Orleans, La., November 23, 1939.
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area too small in many sections to permit a family to do better than eke out a bare living, up to the larger plantation where in some instances hundreds of families are required to carry on the business of the place.

If we were to confine ourselves to the line of attack that seems to be most popular nowadays we would devote our entire time this morning to picturing the very worst that could be found in our social and economic setup. A few years ago this country was engulfed with articles galore telling of the terrible conditions prevailing in the slums and tenament sections of the larger cities of the North. Today's pasttime seems to be the writing of articles and the printing of pictures taken in corresponding slum areas of the rural South. We would have no objection to this except for the fact that many of our friends may get the impression that there is little else in the rural South. How quickly people jump to false conclusions may be illustrated as follows: A few years ago the city of Miami was struck by a tropical storm that did considerable damage. The news of the storm was heralded far and wide. A few weeks later when I remarked to a friend in Nebraska that I had to be in Jacksonville on the following Monday, he turned quickly and said with apparent surprise, "Why! I thought Florida was destroyed by the storm." It's true the storm did a great deal of damage but it barely came within 400 miles of Jacksonville and certainly all Florida lacked a lot of being destroyed. Likewise, in all of the current stories on the privation suffered by certain people in the rural South who can be found and who can be induced to pose for pictures, we trust you will not jump to the conclusion that all the South is like that.

Has it ever occurred to you that the South has more than half of the farm population of the United States? According to the 1935 census the farm population of the South totaled slightly more than sixteen million people or fifty-two per cent of the full farm population of the United States. This large farm population as compared with the rest of the United States has come about for three reasons: (1) The agriculture of the South has been built up largely on what we can characterize as a hand labor basis, which system requires more people in proportion to the cultivated acreage, (2) The South has not had the industries that the North has had to take up the surplus of farm labor, (3) as the saw mills exploiting the South's wonderful stands of virgin timber cut out and abandoned their mills there was nothing for their labor to do but take up small farms on these cut-over lands.

Over a period of many years the South's major production lay in the line of cotton and tobacco, with some scattering development of orchards and truck crops. Each of these crops has the capacity to produce a comparatively high income per acre. As a result human labor could be profitably employed on a next to hand labor basis. One horse plow, one horse cultivator, common garden variety of hoe—all of these barely one step in advance of hand labor. As a result the family worked only a small unit of land. So long as prices were such that the income per acre was good the family was able to meet its modest living requirements on this small acreage.

The same equipment used for the production of cash crops naturally was used for the production of feed crops. But here the cost mounted out of proportion because the return per acre from these crops is in no sense as large as the return per acre from the more important cash crops. As a result farmers of the South could not be induced to diversify their crops and produce more of the things they consumed on the place for the reason that on a hand labor basis the cost of producing these things was out of proportion to the value of the crop produced. So long as prices of their cash crops continued favorable there was little inducement to change from this practice. It is a fact, however, that here and there progressive farmers began to see the light and began to modify their system by the introduction of such improved machinery as they could without serious derangement of their farming activities.

The period from 1930 to 1933 brought the crisis. Heretofore, land owners had been able to make the necessary advances to their tenant families and the prices of crops were such that the tenant family, even though it worked only a small acreage, was able to repay these advances in the fall in most years and be prepared to start out the new year with a clean slate. With the disasters of 1930, 1931, and 1932 this situation changed. Tenants could no longer repay their advances. Land owners reached the point where they no longer could make advances because their own resources were strained to the vanishing point. As one large farmer told me in the spring of 1934, "When the depression started I had $40,000 in the bank. By midsummer in 1933 I was $40,000 in debt. I had 90 families on my place to take care of."

For many, many years as pointed out above labor in the South was cheaper than machinery. By 1931 and 1932 a point had been reached where machine labor was cheaper than man labor. For example, back about 1918 or 1919 I visited a large plantation in the Arkansas Delta. The county agent had been urging this man to add some improved machinery in order to make certain improvements in his management. The land owner took us out. We drove through a a thousand acre field that was being planted to cotton with cheap ponies, one-horse plows, the cheapest of gear. Beyond this field we approached a 500 acre tract where the under-brush had been removed and large trees had been deadened. Weaving back and forth among the deadened trunks again were more light ponies, more cheap harness, more small plows. Pointing to this tract the owner remarked, "this land is making me $15.00 per acre. What do I want with your machinery?"

There came a time when the labor so employed by this man could no longer pay for its advances and the owner was put to it to find ways and means whereby he could provide a living wage for the people he was obligated to take care of. Under such conditions owners were forced to turn to machinery to replace labor that could not make its wage. This movement has become so extensive that today we are going through what may well be called a revolution in the agricultural South.

When you begin to replace men with machinery you have in effect a revolution, whether there is bloodshed or not. You may recall from your history what took place in England when the machinery for textile mills was invented and work that once had been done in the homes of the workers on small improvised looms and spinning wheels was taken to the factories and thousands and thousands of people were thrown out of work. Your history tells of the rioting that followed. Today we are going through a similar change without rioting because up to the present time it has been sufficiently gradual to permit of some readjustment, enough readjustment to keep people from actually going hungry.

Northern labor centers have helped by taking hundreds of thousands of southern workers. Many thousands of farm workers of the South have found some sort of living, such as it is, in the cities of the South. But the rural South is still confronted with a population problem, the problem of providing a way for its millions of people to earn a better livelihood.

For many years farmers of the South could not take advantage of improved machinery to increase their production of cotton with less labor for the reason that labor was necessary in harvesting the crop. In order to have the labor at hand during the harvest season they had to provide employment at other times of the year. Therefore, they continued on a hand labor basis as long as hand labor could make its wage.

Mechanical cotton pickers have been developed on an experimental basis but none has yet been developed to the point where farmers are taking to it and utilizing it. This situation now, however, is being obviated in part by transient labor. California knows the meaning of transient labor. Our strawberry sections have known the employment of transient labor for many years. Texas and Oklahoma have been utilizing transient labor in the harvest of cotton in recent years and now the movement has extended as far East as the Mississippi Delta. The heralded labor troubles in southeast Missouri this past year came about largely in connection with transient labor that had gone into this territory to pick the cotton crop and then was left stranded.

Regardless of what we think is right and wrong, regardless of what we think is the necessary adjustment, there is now a strong and definite move toward the use of more machinery on southern farms. In the necessity for limiting the acreage of cotton in order that production might be more nearly in line with that which could be marketed land necessarily was released. Other crops with a per acre value large enough to permit production on a hand labor basis were not available. To utilize this land, to make it help pay the overhead expense of the farm, machinery had to be introduced so that more acres per family could be worked, so that the family could have the benefit of the return from more acres of land.

To show how rapidly this movement is advancing one probably can best turn to sales figures on tractors in the South. In the state of Virginia where there long has been considerable livestock development and where tobacco is of greater importance than cotton, the number of tractors from 1930 to 1938 increased by only 32%. In

North Carolina where livestock has not occupied the place that it has in Virginia and where cotton is a more important factor the number of tractors has increased by 72%. In South Carolina where similar conditions prevail the increase has been 73%. Coming down to Georgia the increase has been 99%; in Alabama, 92%. And when we strike the great cotton producing state of Mississippi with its rich delta soils and large areas admirably suited for tractor farming we find that the number of tractors has increased by 165%. Arkansas and Louisiana follow closely with 126% and 118%, respectively, while in Texas the number of tractors in the same period jumped from 37,000 to 99,000, or 165%.

What effect does this have on the social and economic problem of the South? Remember the agriculture of the old South was a one man, one mule system—when you replace a mule you replace a man. A friend of ours on a rolling farm in Alabama was showing us an all purpose tractor. "I sold six mules", he remarked, "and bought this tractor. I took a club-footed negro who could not follow a plow and taught him to operate the tractor. He can ride the tractor and cultivate 30 acres of cotton a day." "What became of the six families that were replaced", I asked. "Oh! They found places around here", he answered.

I stepped on to a farm machinery floor in Atlanta. The manager came out and pointed to a large tractor with fertilizer and cultivator equipment and remarked, "the man who buys this tractor can sell fifteen mules." Again, one could not help but think what is to become of the families that it displaced.

Some farmers are buying improved equipment and are able to work out a plan of operation that permits the use of this equipment for the benefit of all the families on the place. Other places over populated even on a hand labor basis can hardly do so well.

Here is the crux of the South's social and economic situation today. With revenue from cotton reduced, with revenue from tobacco not likely to increase greatly, with a present ample production of other high-value-per-acre crops, what is the South to do with its surplus population?

When we turn to more machinery with which to make our production costs less we displace people. When we turn to livestock as an extra source of cash income we find more acreage must go into pasture and low value per acre feed crops, we find more of the work being done by livestock, and again we displace people. Every way we turn in an effort to save ourselves we displace people. This is a serious social and economic problem.

One cannot help but feel that the development of new industries from one end of the South to the other is one of the South's greatest needs, because in that way we might help give employment to people who are not now needed on Southern farms.

Aside from the necessity of introducing machinery to lower production costs, aside from the necessity of developing a livestock industry as a means of gaining new income, let us see what happens even if we had neither of these problems confronting us. I take you to a plateau in Alabama, known as Sand Mountain. Thrifty Anglo-

Saxon stock settled this country some three generations ago. At that time ample land was available. As families increased in size more land was cleared. As boys grew up farms had to be divided and the acreage per family became smaller. The division and re-division has now progressed to the point where it will no longer be possible to subdivide and leave families with sufficient acreage on which to provide a living. Already a tire plant has located near by. A small spinning mill has been built in one of the principal towns in this area, but still the surplus labor has not yet been provided for. Hundreds have left to go to larger cities in the South and in the North and still this area is faced with a problem of over population.

Even if world conditions improve and the prices of farm products rise to old time levels we still will be faced with the problem of providing profitable employment for unneeded farm labor. The only answer to this probably lies in the continued and more rapid expansion of industrial development in the South. More industries, large and small, widely distributed over the South are needed to give relief to the farms of the South now weighted down with this heavy burden.

The large rural population of the South imposes heavy social obligations. Think of the cost of providing schools, churches, community centers, etc., for such a large and scattered population. These problems are further complicated by the fact that people of two races are to be provided for. That means a dual system of schools and churches and community centers as well as other dual facilities. No wonder it has been so difficult to bring up the standards of our rural schools in anything like approximate keeping with those of the cities.

According to the 1935 census we have 3,367,000 farms in the South. But please bear in mind the Census Bureau's definition of a farm. Outside the South where farm labor is paid a cash wage the farm laborer is not classed as a farmer. In the South where much of our farm labor is paid in the form of a share of the crop, the laborer is classed as a farmer and all statistics are averaged in accordingly. When you have occasion to make comparison between the South and other sections we hope you will keep this in mind. If farm labor is to be averaged in one section of the country it should be so included in all sections. A 500 acre farm in another section of country is classed as one farm. A 500 acre farm in the South may be counted as 9 farms because it has one owner and 8 sharecroppers on it. One can easily see how badly figures can be thrown out of line.

Of the more than 3,300,000 farms in the South (census count) 1,700,000 are of less than 50 acres in size. Since the share cropper seldom works more than about 35 acres, it is assumed this group, less than 50 acres in size, includes most of the share croppers. This leaves, however, more than 1,600,000 farms ranging from 50 acres on up. This higher income group furnishes the solid skeleton foundation on which a strong rural buying power of the South rests.

Since we have heard so much about poverty in the South has it ever occurred to you that of all farmers in the United States receiving an annual cash income of $1,000 or above, that more than one-third of them are in the 14 states of the South? The census of 1930 showed more than one million of the farms of the South have an annual cash

income of $1,000 or more. Conservative authorities have estimated that $1,000 cash income on the farm is equivalent to about $1,600 income in the cities.

For the year July 1, 1935, to June 30, 1936, the Bureau of Home Economics, U. S. Dept. of Agriculture, made an exhaustive survey in a study of consumer purchases. A projection of this survey discloses that for that period there were in the United States nearly 3,000,000 high-income farm families with average incomes of $1,907 per year. Of these more than 1,000,000, 36.6% lived in the South. Furthermore, the average income for those of this high-income group living in the South was $2,002. This projection also shows that of all farm money spent in the United States for consumer goods 39.3% was spent by southern farmers; for automotive products 36.2%; for transportation other than by auto 43.7%; for food 39.3%; for clothing 47.1%; for household furnishing 39.6%; for recreation 39.5%; for housing 34.3%; and for personal care (toilet articles, cosmetics, etc.) 40.2%.

Thus you can see, as we stated in the outset, the South is a country of sharp contrasts. Our great problem is population and how to give it gainful employment while readjusting the management of our farms away from the extravagant use of hand labor, trying to strike somewhere that happy balance that will give a comfortable living for all and enable every family to enjoy a fair share of the better things of life.

AGRONOMIC PROBLEMS OF THE SOUTH[1]

M. J. Funchess[2]

NEARLY a year ago your President caught me in an unguarded moment and induced me to consent to prepare a paper for this meeting dealing with the subject, "Agronomic Problems of the South". Before attempting to enumerate and enlarge upon some of the specific problems that the agronomists should tackle in their efforts to improve southern agriculture, let me give you a few comparative figures which picture agricultural conditions in the South. The comparative figures deal with ten southern states that produce a large amount of cotton, and a specific comparison between Alabama and Iowa. The average cash returns from all crops per capita from ten southern states in 1937 amounted to $104. For Alabama, this figure was $73 and for Iowa $77. The cash returns from all livestock and livestock products from the ten southern states was $45, from Alabama $20, and from Iowa $469. Cash returns from all crops, from all livestock, and from Government payments for the ten states was $158, for Alabama $100, and for Iowa $571. These very great differences in per capita income may be readily understood from the following figures. The number of acres of farm land per capita in the ten states was 24, while in Alabama it was 14, and in Iowa it was 35. The number of acres of harvested crops for the ten cotton-producing states was 7, for Alabama it was 5, while for Iowa it was 20. In 1937, Alabama farmers planted 3,493,000 acres of corn that produced an average of 14 bushels per acre, or a total of approximately 49,000,000 bushels of corn. That same year, Iowa farmers planted 9,636,000 acres of corn with an average yield of 45 bushels per acre and a total production of 438,438,000 bushels. The Iowa farmer planted nearly three times as many acres of corn, but produced nearly ten times as many bushels as the Alabama farmer secured for his effort. Alabama farmers had 132,000 acres in oats that produced an average of 24 bushels per acre and a total crop of 3,168,000 bushels. The Iowa farmers planted nearly 6,000,000 acres in oats; produced an average of 33 bushels an acre, and harvested 198,000,000 bushels of oats. These figures relative to acreages and yields readily explain why the average farmer in ten southern states secured a total cash income of $158, and why the Alabama farmer secured a cash income of only $100, while the Iowa farmer secured an average of $571 per capita. It is perfectly clear that southern farmers will not be much better off than at the present time until their production of farm crops is increased. The southern farmer can never produce much in the way of livestock or livestock products until there is an adequate production of feed and forage. These opening statements clearly indicate in a general way the nature of the most important problems that the southern agronomists must tackle.

In the following pages, an attempt is made to present to this group a discussion of some of the unsolved or partially solved agronomic

[1]Presented on the general program of the thirty-second annual meeting of the Society held in New Orleans, La., November 23, 1939.

[2]Director, Alabama Agricultural Experiment Station, Auburn, Ala.

problems of the South. It is not claimed that this is a complete list of problems falling in these categories. Probably the list might be very greatly extended. In presenting this list of suggestions, the views expressed are those of the writer and of the staff of the Agronomy Department of the Alabama Experiment Station. No attempt has been made to make a composite list of problems based on suggestions from other southern experiment station groups.

A glance at reported crop yields from most of the southern experiment stations will show that yields from check plots and from plots receiving good fertilizers are sometimes double or even treble the average crop yields from the particular state in which the report originates. This means that in practically all cases field plot experiments are located on land that is very much more productive than the average land in the area represented. The question might well be raised as to whether or not results from this good land may safely be considered to apply to average land or lands that are poorer than the average. In Alabama, evidence is accumulating which sharply warns us against drawing sweeping conclusions for all kinds of soil, based on experiments conducted on a few kinds of soil. A few examples may be given to illustrate this point. Based on a number of cooperative experiments, our Agronomy Department concluded that mineral fertilizers were rarely needed for corn when it was planted in rotation with other crops which were fertilized. Experiments on our substations supported this opinion. Nevertheless, when the Experiment Station bought some very poor, rolling, sandy land and began to farm it, there was found a need for potash so great that corn almost failed without potash applications. In the Piedmont section of Alabama, erosion has been severe leaving only a thin surface soil. Accumulating evidence strongly indicates that on such land farmers receive very much smaller increases from given applications of fertilizer than are received from land not severely damaged by erosion. These kinds of observations are causing some of us to question pointedly how far it is safe to make recommendations for widely varying soil conditions when the recommendations are based on trials conducted on land far above average productivity. These kinds of results should make the cautious investigator question whether or not he can safely recommend the kind and amount of fertilizer that is most economical for a large number of soils and soil conditions that are not represented in his field experiments. In the lower South, peanuts occupy an ever increasing acreage. A large part of the crop is harvested and sold. Farmers know that harvesting peanuts is hard on the land. What kind of fertilizer should be applied to a crop that follows harvested peanuts? Preliminary and unpublished evidence indicates that the agronomist is unprepared to give a real good fertilizer recommendation for such crops.

The usual fertilizer sold today is considered to be valuable chiefly because of the NPK elements contained. How long will this assumption stand? Without attempting to answer this particular question, it may be pointed out that when land is overlimed it may immediately develop a need for elements in addition to NPK. For certain crops, the evidence indicates that there are many sandy lands in the South

that contain very small amounts of the so-called rare elements. The work of Doctor Sommer at the Alabama Station indicates definitely that the use of pure salts in a cropping system soon develops a condition where NPK alone is quite insufficient for crop production. Under greenhouse conditions, the need for some kind of so-called rare elements is developed after a few years intensive cropping in pots. The continued use of low grade fertilizer may incidentally supply most, or all, of these rare elements. On the other hand, the laws of economics and the production of synthetic materials are driving us toward the use of more concentrated fertilizers. Doctor Tidmore of the Alabama Station has shown a possible saving of $115,000 annually in Alabama if the grade of superphosphate now in use be increased from 16 to 18 per cent of phosphoric acid. Additional savings that might be made through the use of higher grades of other materials and of mixed fertilizers should make a total much greater than that which is possible from the use of higher grades of superphosphate. If concentrated fertilizer becomes more general, the agronomists should be prepared to state whether rare elements are needed and the amount that should be applied to make up the deficiencies in the various soil types. If and when the time comes when rare elements must be applied, the agronomists may be called on to advise the manner of application or the method of incorporating uniformly small amounts of material in the usual fertilizer so as to supply economically the rare elements in question. It may not be considered strictly an agronomic problem, but the agronomists will be involved in finding an answer to the question that is sure to be raised as to the food and feed value of crops grown on land that is deficient in some of the rare elements. This rather extended discussion of the possible needs of rare elements in fertilizer should not mislead anyone to conclude that there may be an urgent need for their application in fertilizer now. This discussion is intended to bring out the possibility of the need for both extensive and intensive work in the future to answer questions along this line, which questions might be quite important when they develop.

Soil erosion and the ill effects of soil erosion are topics of discussion by a horde of agricultural workers. Funds available for study and control of soil erosion amount to a sum greater than that available for any other subject studied by experiment stations and the Department of Agriculture. Nevertheless, it is probably true that we know less about soil erosion and methods of control than we do about many other agricultural problems. It is generally assumed that organic matter plays an important part in the control of soil erosion, but one would probably get a vague answer if one requested definite proof. Who knows the function or the functions of soil organic matter? Who knows the possible importance of the part organic matter plays in stimulating biological activities in soil? To push this thought further, one might ask who knows the importance of biological activities? Is it not probable that we have been putting a disproportionate amount of emphasis on soil chemistry and more or less slurred over the possible importance of soil physics and soil biology? Many of us possibly have seen great volumes of water flowing over bare soil

without any evident erosion. In such cases, apparently the soil was held against erosion by some kind of organic growth. This is an observation and not a statement of fact. If it is found to be true, what part does active soil organic matter play under such conditions? Is soil organic matter important because it holds much water, or is it important because it helps conserve soil water? Or is it important because of its binding power, or its value as food for soil organisms? Why are gall spots proverbially poor? Gall spots contain little or no organic matter. Soil in such spots may contain just as much mineral nutrients as in uneroded areas. Nevertheless, even with commercial nitrogen added, gall spots usually produce little or no crops. Usually the gall spots are the only ones on which a stand of crop fails. Does the gall spot suffer more from drouth than uneroded land? Someone may try to answer these questions, but if convincing evidence is asked for to back up the answer, it is extremely doubtful if such evidence would be forthcoming. This leads to a question as to the possible value of barnyard manure. Is it valuable only for its NPK content? Even though this question may have been answered in the affirmative by someone, there are many who do not accept such an answer. When manure is applied to a gall spot, the results are striking. However, the equivalent amount of commercial fertilizer may fail almost completely to produce a crop. Applications of manure have controlled root-rot of cotton while commercial fertilizers had no effect on it. What is the value of organic matter in making mineral nutrients available? Much work has been done along this line, but we do not have an answer that explains fully the results. For example, Scarseth, formerly of the Alabama Experiment Station, accurately determined that available phosphates when applied to bare soil in pots in the greenhouse became quite unavailable in one season. However, on the same soil in the field, a heavy application of phosphate has continued to give a splendid response four years after the application was discontinued. There is no definite explanation for the difference between the results obtained in the field and those obtained on bare soil in pots in the greenhouse. May we assume that this difference is due to the action of soil organic matter and plant roots and plant residues? This discussion leads to still another question. If the changing agricultural conditions bring about an increase in grazing crops and more winter cover crops in the South, will there not need to be developed through experimentation another set of fertilizer recommendations for these changed conditions? If more crops are grazed on the land, might there not be a reduced need for mineral fertilizers and nitrogen? Might there not be needed a different ratio under such conditions from that needed under the present conditions where row crops largely prevail?

With the exception of certain small areas, practically all cultivated lands in the South are acid to some degree. However, liming is not generally practiced. This is due in part to the fact that the system of farming usually followed does not include crops that respond well to lime. There are indications that the farm program on thousands of southern farms will be materially changed in the next few years. The change that is most likely will be to a system that would include

crops which frequently respond to lime. There is an urgent need, therefore, for a "quick test" that would determine where lime would pay. Note especially that emphasis is put on whether or not lime will pay. There may be a number of methods that will determine whether or not a sample of soil is acid to some degree. However, it is extremely doubtful if there are methods available now that answer the all-important question of the farmer, "Will it pay me to lime this particular field?" An example may illustrate this point. A number of years ago the Alabama Station established an experiment field in the Piedmont area. Chemical tests indicated the soil to be very slightly acid. Nevertheless, an application of lime nearly doubled the yield of cowpeas the first year. When it was understood that cowpeas are supposed to be an acid tolerant crop, the complete failure of the chemical method in this case is evident.

As the type of farming changes in the South, important liming questions should be answered, such as, how much lime will be needed on a given soil under a given system of farming? Should small amounts be applied annually, or may large amounts be applied at infrequent intervals? Are small particles of lime actually washed into the subsoil when sandy soils are limed? On what soils may a reasonably pure calcium lime be applied and where should a dolomitic lime be used? How much lime will different soils stand before overliming injury is obtained? All of these are practical questions that should be tackled now so that answers will be available when a changed type of farming in the South calls for such answers.

This leads to a brief discussion of quick tests in general. Earlier in this paper it was indicated that there was a great need for information relative to the fertilizer needs of soils under a vast number of conditions not represented by the usual field test. The soil chemists may render an extremely valuable service through the development of really reliable quick test methods to determine fertilizer needs on various soils and for various crops not now represented by field tests. Reliability of such tests must be beyond reasonable doubt. Farmers now use from twelve to twenty million dollars worth of fertilizer in each of several southern states. Fertilizer practice that involves such huge sums of money must be on as firm basis as possible. Farmers should not be the victims of poor judgment and bad advice based on faulty methods.

While we are still talking about fertilizers and soil amendments in general, it might be profitable to discuss briefly several questions relative to the leaching of fertilizers. It appears to be generally assumed that certain nitrogenous fertilizers are quite readily leached from soils and that most nitrogenous fertilizers may be leached fairly easily. Accumulating evidence indicates that on certain soils the danger of leaching is almost nil even if nitrates are used. On the other hand, on sandy soils and in humid climates, nitrogen losses from leaching may be severe. There is some evidence that indicates considerable loss of mineral elements by this means also. But there is no great amount of available information relative to losses of nitrogen by leaching, under field conditions. In connection with the mineral elements, there are but few carefully conducted, convincing experiments to show the

extent of leaching losses. In most cases, southern farmers apply more phosphoric acid than is removed in the crop. In the case of truck farming, many times more mineral elements are applied than are removed in the crop. Is there a single agronomy department in the South that can present a clear-cut picture of the final disposition of applied mineral fertilizer elements? How much of such material is lost by erosion? How much of it is lost by filtration into the subsoil? How much of these losses, if any, may be prevented by different and better cropping systems? When it is recalled that millions of dollars are spent annually for fertilizers in the South, it immediately becomes apparent that these types of questions are pertinent.

If the question be asked, what is the object of land preparation?—both the soils men and the agricultural engineers would probably feel that it is their job to answer this question. The chances are good that neither has a good answer. Is the same type of preparation needed on sandy soils as that which may be necessary on the clay loams and clays? Who knows what soil structure is best for biological activities and the production of plants under a given set of conditions? Why do some soils erode much more rapidly than others even though the slope and cover may be identical? Is this difference in erodibility due to structure alone, or is it due to a difference in organic content, or both? If due to a peculiar soil structure, could such a structure be changed by practical means? What are the objects of cultivation? What is accomplished by the cultivation of a crop beyond weed control? May we not devise methods of planting and cultivation that will reduce the labor charge against some southern crops which now have a high labor requirement? All of these are subjects worthy of the best effort of the agronomists, and if need be, the agricultural engineer, cooperating. Possibly it may be turned around and the burden of responsibility placed jointly on these two groups of people, since neither one alone has the training, the background, and experience to handle these types of projects satisfactorily.

A large percentage of the farms in the cotton belt of the South are without improved pastures. Real pasture land occupies a very small percentage of the land in farms. In recent years, there has been a steady increase in the interest in livestock and in pasture production. Unfortunately, the agronomists have done but little in the interest of pasture development. To be sure, there are a few pasture experiments, but there is only limited information relative to the subject that is known to be applicable over a wide range of soil conditions. In the main, the pasture problem in the South hinges around the maintenance of nitrogen. The chief pasture problem, therefore, will deal with legumes suitable for pastures under southern conditions. Many southern soils are so poor that they will probably produce pasture plants with such a low mineral content that animals will suffer from mineral deficiencies when grazed on these lands. The agronomists should determine the limit of these areas and find the necessary correctives for such lands if direct mineral feeding does not solve the problem. The limited work that has been done on pastures has already developed some real research problems. May there be a combination of legumes that will last through both summer and

winter? Such a combination would make an ideal hog pasture. What combination of legumes and grass will make the best pasture? Can there be found a summer growing legume with a winter grass, or may this be reversed to have a winter legume and a summer grass? Regardless of the angle from which the problem is attacked, the main questions to be solved relate to the production of the legume. Then, there is the question of certain smothering crops like hop clover. These may appear to be very desirable, but when the severe smothering effect of such a crop is observed, one might be lead to question whether hop clover is desirable in a pasture. At the present time, white clover appears to be the best legume for pasture production. On what soils will it grow well? What treatments are necessary on soils where it does not naturally do well? On what soils will it need lime? What strain of white clover is best? Can good pastures be made on common southern uplands? If so, what plants will be used? Will it be better to try to produce temporary pasture plants on uplands than to try to depend on permanent pastures? Is drouth more severe in its effects on permanent pasture or temporary pastures on uplands? At the present time, permanent pastures are much more prominent than temporary pastures. The effect of severe drouth on permanent pastures is well-known, and when livestock farmers have their pastures so badly burned by drouth that they must resort to buying feed to tide them over the distress period, they well remember it. How far may temporary grazing crops be supplied to carry livestock through such drouth periods when the permanent pastures are burned out? Experiments in management on the Black Belt Station in Alabama indicate that this is one of the most important fields of experimentation. All these kinds of pasture problems must be tackled by the agronomists if a foundation is to be laid on which the animal husbandmen may build a reasonably profitable livestock production program in the South.

In all probability, the greatest opportunity for service by the agronomists of the South lies in the field of plant breeding. Aside from a great deal of breeding work done on cotton, plant breeding operations by the several experiment stations have been rather limited in scope until the last few years. Recently, a few of the southern stations have started rather extensive plant breeding programs; however, the field has scarcely been touched. Some of the needs that might be met through the operations of the skilled and well-trained plant breeder are listed in the following paragraphs.

In the southeastern states, vetch, Austrian peas, and crimson clover are common winter cover crops. These are now planted to the extent of some 45 or 50 million pounds of seed annually in the three states of Georgia, Alabama, and Mississippi. Vetch and Austrian peas are both subject to a number of destructive diseases. If disease resistant strains of either of these, or both of these, were available, the winter cover crop program could be put forward more rapidly than it is moving at this time. Neither vetch nor Austrian peas is a good seed producer. Many millions of pounds of seed are bought annually. The necessity of buying seed and the scarcity of cash with which to buy seed are factors that operate seriously against the expansion of

the use of these two crops for soil cover and improvement. If there were available in the South a strain of vetch or Austrian peas that was highly resistant to disease and produced seed freely, the winter cover crop program in the South could be made very much more effective and extensive than it is. Crimson clover is fairly well adapted to much of the southeastern states. It would be a much more valuable crop if it had a considerable percentage of hard seed, which would enable the grower to use it without the necessity of reseeding each year. A crimson clover strain that matured earlier than the common variety would be highly desirable.

Common lespedeza is found on a wide range of soils throughout the entire southern states. Among its weaknesses are its slow growth in early spring and its small root system. It might be a more serviceable crop if it had more hard seed. If some plant breeder will produce a much more vigorous strain of common lespedeza, and especially a strain with more vigorous root system, the possible value of such an improved strain would be difficult to forecast. Lespedeza sericea is a crop of considerable promise, but as long as farmers must grow a strain with a high tannin content, the crop will not be as valuable as it could be. The plant has a tendency to shatter its leaves very easily. It is also a little coarse. Why can't some energetic plant breeder develop a strain of Lespedeza sericea that has fine stems, that holds it leaves well, and that has a low tannin content?

Among the grasses, Dallis and Bermuda are the most common in pastures in the South. At the Georgia Coastal Plains Station, breeding work is under way to secure an ergot-free strain of Dallis grass and an improved strain of Bermuda grass. Even a casual inspection of the work under way at that Station indicates the almost unlimited possibilities for improvement in these two varieties of pasture grasses. The quality of bluegrass as a pasture plant is well-known throughout the livestock producing areas above the Cotton Belt. The crop does not do well in the greater part of this area. Is it too much to hope that the plant breeder could secure a strain that could be grown much further south than bluegrass is now supposed to be adapted? If bluegrass could be added to the other pasture grasses, more rapid improvement in pasture in the Cotton Belt could be effected. In the light of existing information, white clover is the most promising legume for pasture development in the South. The crop will stand severe cold and is adapted to a considerable range of soil and climatic conditions. Plant breeders interested in pasture development should find in white clover a crop that challenged the best that is in them. By the latter part of May, due to heat or drouth or to both of these, white clover usually disappears from pastures. This is particularly true on upland. In moist positions, white clover may persist through a good part of the summer. This leads to speculation as to the possibility of discovering strains sufficiently resistant to drouth and hot weather to enable them to grow throughout most of the summer months. The crop does best on lands that are only slightly acid. May not acid-tolerant strains be found? An acid-tolerant strain of white clover might extend its use over countless thousands acres of land that would need to be limed for the usual strains of white clover.

There are already several existing strains of this plant, but it is quite probable that the possibility of improvement through selection and hybridization has scarcely been touched. Since the maintenance of nitrogen is fundamental in the maintenance of southern pastures and since white clover has a growing season that fits in well with the present pasture program of a legume and a grass, the potential value of this crop in southern pastures can scarcely be over-estimated.

Peanuts now occupy a large acreage in the southeastern states, and the importance of the crop is increasing. But little work has been done on peanut improvement except at one or two experiment stations. The possibility of increasing the yield through plant selection and hybridization has scarcely been touched. Most kinds of peanuts are subject to a number of diseases. Few of these diseases can be economically controlled by application of chemicals. Might not the plant breeder provide disease-resistant strains of peanuts just as we now have wilt-resistant cotton, rust-resistant wheat, etc? Some varieties of peanuts produce a high percentage of "pops". Is it too much to expect that some plant breeder might take an otherwise desirable variety of peanut and increase the production by breeding for freedom from "pops"? Some of the best varieties of peanuts have too long a growing season to fit into a farm program near the upper limits of the Cotton Belt. The so-called Alabama or North Carolina runner is in this class. If some plant breeder could produce a high-yielding strain of this type of peanut that would mature three or four weeks earlier than the strains now being used, the area suitable for producing peanut-fed hogs could be greatly extended. In certain sections, soybeans are being grown chiefly for their oil content. Is it not possible to produce a high-yielding strain of peanuts with a high oil content that would enable southern farmers to grow peanuts for the oil content just as some Corn Belt farmers are now growing soybeans for oil? A considerable part of the southern peanut crop is harvested. Where runner peanuts are harvested, farmers lose from 15 to 20 per cent by having them stripped off in the soil when the plants are plowed up. To be sure, these shattered peanuts may be salvaged by hogs. There are thousands of tenants who do not have hogs with which to salvage these peanuts. A non-shattering strain would increase the value of harvested peanuts under these conditions to the extent of possibly covering the cost of production.

The so-called rust-resistant varieties of oats, like Texas Rust Proof, have but little rust resistance when planted near the Gulf Coast. Frequently, farmers in areas within 100 miles of the Gulf Coast lose their oats entirely because of rust damage. The production of a high-yielding strain of oats that would be resistant to rust under these conditions would be a very valuable addition to the crops available for use on thousands of farms. Oats are frequently subject to lodging under the weather conditions existing in the South. A strain with a straw sufficiently stiff to stand up under southern thunderstorms would be highly valuable.

There might be listed a number of problems in connection with breeding corn for the southern states. One of the most important is the production of a high-yielding variety with shuck covering that is

long and tight enough to protect the ear from the ravages of weevils and ear worms. Superior yielding strains or hybrids cannot make much of a showing on land that produces, say, 15 bushels per acre. Where high yields are possible, there is great need for better yielding kinds of corn.

The most important cotton breeding problems involves improvement of quality, yield, and disease resistance. It has taken the cotton breeder many years to combine high yield with good quality. However, much progress has been made along this line in recent years. Yet, there remains much to be done. This is particularly true in areas where cotton wilt is severe. There is room for much improvement in the quality of the wilt-resistant strains and varieties now available. The plant breeders are still struggling with breeding methods in connection with wilt resistance. Apparently, there may be a number of strains of wilt. If there are not a number of strains of wilt, then it appears that a given strain may act differently in different soils and at different fertility levels. The plant breeder has found more or less difficulty in uniformly inoculating soils with wilt organisms. How far do the different fertility levels influence susceptibility to wilt? How far do adequate amounts of the common plant nutrients, particularly potash, affect susceptibility to wilt? To what extent might strains of cotton be developed that are resistant to the seedling diseases that frequently injure the stands of cotton? There appears to be almost unlimited opportunities for the improvement of cotton along the general lines indicated by these suggestions and questions.

The agronomists may not realize it, but on their shoulders may rest the responsibility for building an improved farm program for the South. It is not enough for the specialists to turn out isolated pieces or research and leave the application of such results to someone else. When research findings are given to the public, the researcher who is most valuable is the one who can see clearly where his results will apply and goes about teaching the public where and how they may be applied. However, the agronomist should avoid becoming a "promotionist". It is unfortunate when we feel that it is up to us to "push our line". As specialist in agronomy, the best service is rendered when the worker is familiar enough with the farm problem to help work his findings into the farm program where he serves. If he does not, who will?

As a final topic, let me discuss briefly a subject that is not agronomic, but that is of interest to all agronomists in particular and to all agricultural workers in general. It is necessary to scan only a few advertisements to find cases where either an individual, a firm, or a corporation is advertising some kind of seed or some kind of fertilizer in a way that is misleading to the prospective purchaser. In these instances the fertilizer and seed advertisements completely ignore recommendations of experiment stations. Through extensive advertising the attempt is made to induce farmers to use fertilizers and materials that are unsatisfactory both as to the ratio of the elements and the amounts applied. Seed advertisers make extravagant and unsupportable claims as to the yield and the quality of the crop that can be made by planting the particular variety that they have to sell.

After large amounts of public funds have been spent in the interest of agronomic experiments to determine the best variety of a given crop or the best fertilizer practice for farmers in an area or in a state, the agronomists in particular and all agricultural workers in general should feel a responsibility to counteract the effect of false and misleading advertising by those who may have seed or fertilizer for sale which do not fit in with the program for a given area or state. Fortunately, the amount of such bad advertising is small. Nevertheless, it should be our responsibility to try to protect farmers against those people who apparently have little or no interest in the welfare of the consumer, but appear rather to take the attitude that let the buyer beware.

This incomplete list of agronomic problems indicates that the agronomists who serve best in the South in the future will put much less emphasis on cotton than they have in the past and will put increasing effort into the development of a feed, forage, and pasture program on which may be based an increased production of livestock with which to balance the South's cotton crop.

A GENETIC STUDY OF MATURE PLANT RESISTANCE IN SPRING WHEAT TO BLACK STEM RUST, *PUCCINIA GRAMINIS TRITICI*, AND REACTION TO BLACK CHAFF, *BACTERIUM TRANSLUCENS*, VAR. *UNDULOSUM*[1]

C. L. PAN[2]

DURING the last 20 years, numerous attempts have been made to breed hard red spring wheats that are resistant to stem rust and otherwise desirable. The present investigation was made to study the genetic nature of stem rust reaction under field conditions to many physiological races, using for these studies crosses between several rust-resistant spring wheats. Opportunity presented itself to study the nature of inheritance of resistance to black chaff.

MATERIALS AND METHODS

A brief description of the parental material will be of interest. Marquis×H44, III–31–7, was obtained from the Dominion Rust Research Laboratory, Winnipeg, Canada. It is resistant to stem rust but susceptible to black chaff. Pentad× Marquis, III–34–1, also obtained from the Dominion Rust Laboratory, is semi-resistant to stem rust and resistant to black chaff. Double Cross, II–21–80, from the Minnesota Experiment Station, was obtained from the cross (Marquis× Iumillo)×(Marquis×Kanred). It combines moderate resistance from the Iumillo durum parent in the mature plant stage under field conditions to many physiological races of stem rust with immunity to the stem rust races to which Kanred is immune in the seedling stage. Hope and H44, obtained by McFadden from a cross of Yaroslav emmer×Marquis, are resistant under field conditions to both stem and leaf rust.

F_2 plants of the cross III–31–7×III–34–1 were grown in the greenhouse during the winter of 1933–34 and the parents, F_1, F_2, and F_3 generations were grown in the rust nursery either in 1934 or 1935 or in both years under an epidemic induced by using rust races available and prevalent in the spring wheat area.

New crosses were made between Marquis×Hope, III–31–7, with Hope and H44, and the parents and F_1 generation grown in 1934 and 1935 under stem rust epidemic conditions while the F_2 backcrosses were grown in 1935.

Crosses were also made between Pentad×Marquis, III–34–1, with Double Cross, II–21–80, H44, and Hope. The parents, F_1, F_2, and backcrosses were grown either in 1934 or 1935 or in both years in the rust nursery.

An epidemic of stem rust was produced artificially while black chaff developed naturally. Plants were classified for reaction to stem rust and to black chaff.

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[2]Senior plant breeder and acting head of the Department of Rice of the National Agricultural Research Bureau of China. The writer wishes to express his appreciation to Dr. H. K. Hayes, Professor and Chief of the Division of Agronomy and Plant Genetics, University of Minnesota, for his valuable advice in methods of conducting this experiment and in the preparation of this manuscript.

EXPERIMENTAL RESULTS

REACTION TO STEM RUST

Marquis×H44, III–31–7×Minn. Double Cross, II–21–80.—The data given in Table 1 show that most of the parental plants or rows of Marquis×H44, III–31–7, were resistant to stem rust while Minn. Double Cross, II–21–80, was mostly classified as semi-resistant. Considerable variation in rust reaction was found within each of the parents, which may be due partly to mechanical mixture or natural crossing. Such variation had also been found by Hayes, *et al.* (4)[3] and by Ausemus (1).

There were 357 F_2 plants grown in the field in 1934, 185 being classified as resistant, 102 semi-resistant, and 70 as susceptible. The F_2 plants grown in 1935 were classified as 230 resistant, 137 semi-resistant, and 74 susceptible.

From backcrosses of F_1 of II–31–7×II–21–80 to the resistant parent Marquis×H44, III–31–7, 82 resistant, 20 semi-resistant, and 6 susceptible plants were obtained. The six susceptible plants were rather unexpected. One of the parental plants of Marquis×H44, III–31–7, used for the backcross probably was genotypically susceptible since one such plant was obtained from that parent grown in 1934.

The plants obtained from the backcross of F_1 to the semi-resistant parent, Minn. Double Cross, II–21–80, were classified as 28 resistant and 31 semi-resistant, being very close to a ratio of 1:1.

Of the F_3 lines grown in 1934, 9 bred true for resistance, 5 bred true for semi-resistance, 24 bred true for susceptibility, 28 segregated for resistance and semi-resistance, 20 segregated for resistance and susceptibility, 49 segregated for resistance, semi-resistance, and susceptibility, and 9 segregated for semi-resistance and susceptibility.

The results so far discussed may be explained by assuming that Minn. Double Cross, II–21–80, has two complementary factors for semi-resistance, i.e., in the presence of these two genes semi-resistance is produced and Marquis×H44, III–31–7, carries a single dominant gene for resistance. Accordingly, the F_1 plants would be resistant and in F_2 a ratio of 48 resistant, 9 semi-resistant, and 7 susceptible would be expected. The F_2 results obtained in the 2 years did not agree well with the expected ratio on account of too few resistant plants. However, the proportion of semi-resistant and susceptible plants indicated a good agreement with a ratio of 9:7. The F_3 progenies from a random selection of F_2 plants agreed fairly well with the hypothesis. The data from the backcross, in general, could be explained by the hypothesis. The F_4 reactions also were in fair agreement with the hypothesis suggested. It seems probable that the results of the present study can be explained logically by the proposed hypothesis which was made on the basis of facts actually found by many previous workers. Close agreement between theory and results can not be expected when the parental reactions show as wide fluctuations as in the present study.

[3]Numbers in parenthesis refer to "Literature Cited", p. 115.

TABLE 1.—*Mature plant reaction to stem rust under field conditions of parent, F_1, F_2, and backcrossed plants, and in parent rows and F_3 and F_4 lines grown in 1934 and 1935.*

Parents and generations	Plant, lines or rows	Years	Parental reaction	No. of plants, rows or lines showing indicated reaction*							Total
				R	SR	S	R–	H–	H	S–	
Marquis × H44, III-31-7	Plants	1934		752	40	1	—	—	—	—	793
Marquis × H44, III-31-7	Plants	1935		80	2	—	—	—	—	—	82
Minn. Double Cross, II-21-80	Plants	1934		32	736	24	—	—	—	—	792
Minn. Double Cross, II-21-80	Plants	1935		1	73	—	—	—	—	—	74
III-31-7 × II-21-80, F_1	Plants	1934		11	—	—	—	—	—	—	11
III-31-7 × II-21-80, F_2	Plants	1934		185	102	70	—	—	—	—	357
III-31-7 × II-21-80, F_2	Plants	1935		230	137	74	—	—	—	—	441
Marquis × H44, III-31-7 × F_1	Plants	1935		82	20	6	—	—	—	—	108
Minn. Double Cross, II-21-80 × F_1	Plants	1935		28	31	0	—	—	—	—	59
Marquis × H44, III-31-7	Rows	1934		34	—	—	9	—	—	—	43
Marquis × H44, III-31-7	Rows	1935		10	—	—	—	—	—	—	10
Minn. Double Cross, II-21-80	Rows	1934		—	30	—	6	—	—	9	45
Minn. Double Cross, II-21-80	Rows	1935		—	9	—	1	1	—	—	11
III-31-7 × II-21-80, F_3	Lines	1934	Random	9	5	24	28	20	49	9	144
III-31-7 × II-21-80, F_4	Lines	1935	R	52	0	0	17	0	12	0	81
III-31-7 × II-21-80, F_4	Lines	1935	SR	1	5	—	2	2	4	0	14

*R = resistant; SR = semi-resistant; S = susceptible; R– = lines or rows segregating for R and SR; H– = segregating for R and S; H = segregating for R, SR and S; and S– = segregating for SR and S.

Marquis×H44, III-31-7,×Hope and H44.—The F_1, F_2, and backcrosses were studied to determine whether the same factor or factors was responsible for stem rust reaction. All plants grown were classified as resistant except 4 out of a total of 196 plants of III-31-7 that were classified as semi-resistant. The data clearly show that no segregation existed in these two crosses, indicating that the genetical factor or factors governing the rust resistance of the parent Marquis ×H44, III-31-7, is or are allelomorphic to the factor or factors for resistance in Hope and H44.

Pentad×Marquis, III-34-1×Minn. D. C. II-21-80 and Pentad ×Marquis, III-31-1×Hope and H44.—The great preponderance of semi-resistant plants in F_1 and F_2 and in the backcrosses for Pentad ×Marquis, III-34-1×Minn. Double Cross, II-21-80, showed that the two complementary factors for semi-resistance in Minn. Double Cross, II-21-80, are also present in Pentad×Marquis, III-34-1, although modifying factors of minor importance may be present (Table 2).

It should be noted that five plants of the parent, Pentad×Marquis, III-34-1, out of 69 were classified as susceptible. It seems probable that these variations are due to fluctuations and accordingly a certain proportion of similar plants should be obtained in F_2 and in backcrosses to III-34-1. The results of the crosses between III-34-1 with Hope and H44 agree fairly well with the hypothesis that two complementary factors are responsible for the rust reaction of Pentad× Marquis, III-34-1 and that these factors are not closely linked with the factor or factors responsible for stem rust reaction of Hope and H44.

The experimental results presented have suggested an hypothesis which explains the results fairly well for all crosses studied and also is in agreement with conclusions reached by previous workers. The parental variety, Marquis×H44, III-31-7, proved to be resistant to stem rust in the mature plant stage in the field. The resistant factor in this variety was of course obtained from the parent, H44. According to Hayes, *et al.* (4) and to Neatby and Goulden (5), H44 carries a single genetical factor for resistance; consequently, the parent Marquis×H44, III-31-7 must also have that gene governing its resistance. When this parent was crossed to H44 and Hope, all hybrid plants were resistant, there being no segregation. Indirectly, a genetic factor for resistance in the Hope parent proved to be allelomorphic to the one for the H44 type of resistance. This conclusion is logical because Hope and H44 were sister selections from the cross Yaroslav emmer×Marquis. However, according to Neatby and Goulden (5), Hope has an entirely different genotype for rust resistance, although it is a sister selection of H44-24. The results given here do not support their conclusion.

Hayes, Stakman, and Aamodt (3) found that the Marquillo type of resistance was governed by the interaction of two complementary factors when it was crossed with Marquis×Kanred. Neatby and Goulden (5) also found that Minnesota Double Cross carries two complementary factors for semi-resistance. The data obtained from

TABLE 2.—*Reaction to stem rust in F_1, F_2, and backcrossed plants.*

Crosses and generations	Year	No. of plants showing indicated reaction			
		R	SR	S	Total
Pentad × Marquis, III–34–1	1934 and 1935	6	58	5	69
Minn. Double Cross, II–21–80	1934 and 1935	1	78	—	79
Hope	1934 and 1935	110	—	—	110
H44	1934 and 1935	82	—	—	82
Pentad × Marquis, III–34–1 × Minn. Double Cross II–21–80 F_1	1934	1	13	—	14
Pentad × Marquis, III–34–1 × Minn. Double Cross II–21–80 F_2	1935	68	429	25	522
Pentad × Marquis, III–34–1 × F_1	1935	2	23	2	27
Minn. Double Cross II–21–80 × F_1	1935	5	32	1	38
Pentad × Marquis, III–34–1 × Hope, F_1	1934	5	—	—	5
Pentad × Marquis, III–34–1 × Hope, F_2	1935	199	72	10	281
Pentad × Marquis, III–34–1 × F_1	1935	31	40	7	78
Hope × F_1	1935	54	1	—	55
Pentad × Marquis, III–34–1 × H44, F_1	1934	11	—	—	11
Pentad × Marquis, III–34–1 × H44, F_2	1935	403	143	11	557
Pentad × Marquis, III–34–1 × F_1	1935	27	28	3	58
H44 × F_1	1935	70	—	—	70

TABLE 3.—*Reaction to black chaff under field conditions of parent, F_1, F_2, and backcrossed plants, and in parent rows and F_3 and F_4 lines grown in 1934 and 1935.*

Parents and generations	Plants, lines or rows	Year	Parental reaction	No. of plants, rows or lines showing indicated reaction			
				T*	TM	M	Total
Marquis×H-44, III–31–7	Plants	1934		268	—	525	793
Marquis×H-44, III–31–7	Plants	1935		6	—	76	82
Minn. Double Cross, II–21–80	Plants	1934		788	—	4	792
Minn. Double Cross, II–21–80	Plants	1935		73	—	1	74
II–31–7×II–21–80, F_1	Plants	1934		—	—	11	11
II–31–7×II–21–80, F_2	Plants	1934		230	—	127	357
II–31–7×II–21–80, F_2	Plants	1935		219	—	222	441
Marquis×H-44, III–31–7×F_1	Plants	1935		14	—	94	108
Minn. Double Cross, II–21–80×F_1	Plants	1935		34	—	25	59
Marquis×H-44, III–31–7	Rows	1934		1	42	—	43
Marquis×H-44, III–31–7	Rows	1935		—	1	9	10
Minn. Double Cross, II–21–80	Rows	1934		45	—	—	45
Minn. Double Cross, II–21–80	Rows	1935		8	—	3	11
III–31–7×II–21–80, F_3	Lines	1934	Random	53	81	10	144
III–31–7×II–21–80, F_4	Lines	1935	T	7	48	7	62
III–31–7×II–21–80, F_4	Lines	1935	M	2	18	13	33

*T = trace, M = medium, TM = both trace and medium reaction.

the cross Marquis×H44, III–31–7,×Minn. Double Cross II–21–80, agree in general with the previous conclusion.

The genetical basis for rust reaction of the parental variety, Pentad×Marquis, III–34–1, has not been reported previously. This wheat proved to be semi-resistant to stem rust in the mature plant stage in the field. One of its parents, Pentad, is a 14-chromosome durum wheat. Minn. Double Cross, II–21–80, was a sister selection of Thatcher obtained from the cross, (Marquis×Iumillo)× (Marquis ×Kanred), Iumillo belonging to the same species as Pentad. With this similarity of origin, it is logical that the parent, Pentad× Marquis, III–34–1, may have the same general genetical constitution for rust reaction as Minn. Double Cross, II–21–80, although there is some evidence of minor differences which may result from minor modifying factors. When these two parents were crossed, most of the hybrid plants were semi-resistant.

REACTION TO BLACK CHAFF

An epidemic of black chaff developed naturally in 1934 and 1935. This gave the writer an opportunity to study the genetic nature of resistance to black chaff. The data given in Tables 3 and 4 show this character to be even more variable than that for stem rust reaction. Marquis×H44, III–31–7, Hope, and H44 were moderately susceptible, while the Double Cross, II–21–80, and Pentad×Marquis, III–34–1, were apparently resistant. Segregation was present in the crosses Marquis×H44, III–31–7,×Minn. Double Cross, II–21–80; Pentad×Marquis, III–34–1,×H44; and Pentad×Marquis, III–

TABLE 4.—*Reaction to black chaff of parents, F_1, F_2, and backcrossed plants in 1934 and 1935.*

Parents and generations	Year	No. of plants showing indicated reaction		
		T	M	Total
Pentad×Marquis, III–34–1	1934	5	—	5
Pentad×Marquis, III–34–1	1935	82	—	82
Minn. Double Cross, II–21–80	1934	5	—	5
Minn. Double Cross, II–21–80	1935	74	—	74
Hope	1934	—	11	11
Hope	1935	2	97	99
H-44	1934	2	16	18
H-44	1935	3	61	64
III–34–1×II–21–80, F_1	1934	14	—	14
III–34–1×II–21–80, F_2	1935	521	1	522
Pentad×Marquis, III–34–1×F_1	1935	27	—	27
Minn. Double Cross, II–21–80×F_1	1935	38	—	38
Pentad×Marquis, III–34–1×Hope, F_1	1934	1	4	5
Pentad×Marquis, III–34–1×Hope, F_2	1935	102	179	281
Pentad×Marquis, III–34–1×F_1	1935	51	27	78
Hope×F_1	1935	2	53	55
Pentad×Marquis, III–34–1×H-44, F_1	1934	6	5	11
Pentad×Marquis, III–34–1×H-44, F_2	1935	208	349	557
Pentad×Marquis, III–34–1×F_1	1935	33	25	58
H-44×F_1	1935	11	59	70

34–1×Hope, whereas most of the plants of the crosses Marquis×H44, III–31–7 and H44 and Marquis×H44, III–31–7×Hope were moderately susceptible and only one out of several hundred hybrid plants of the cross Minn. Double Cross, II–21–80, ×Pentad×Marquis, III–34–1, was moderately infected with black chaff, the rest being apparently resistant. The reaction shown by the F_1 plants of the different crosses indicated that susceptibility was dominant to resistance.

It seems undesirable to attempt a genetic explanation of the manner of reaction to black chaff, but the data clearly demonstrated that resistance and susceptibility were definitely inherited and furthermore showed a general agreement with the conclusions of Bamberg (2), Ausemus (1), and Hayes *et al.* (4).

A study was made to determine the extent of association, if any, between reaction to stem rust and black chaff. The data were analyzed by X^2 for independence and the results are given in Table 5.

The X^2 values of different crosses indicated that association was present. Resistance to stem rust was associated with susceptibility to black chaff. Hybrid plants that are resistant to both diseases were obtained showing association was not complete, but no single plant susceptible to both was found.

TABLE 5.—*Results of X^2 test for independence between reaction to stem rust and black chaff.*

Crosses or generations	Year	D/F	X^2 value
Marquis×H44, III–31–7×Minn. Double Cross, II–21–80, F_2	1934	2	57.8
Marquis×H44, III–31–7×Minn. Double Cross, II–21–80, F_2	1935	2	210.7
Marquis×H44, III–31–7×F_1, (Marquis×H44)	1935	2	58.9
Minn. Double Cross, II–21–80×F_1, (III–31–1×II–21–80)	1935	1	34.5
(III–31–1×II–21–80), F_3	1934	12	117.5
(III–31–1×II–21–80), F_4	1935	8	71.7
Pentad×Marquis, III–34–1×Hope, F_2	1935	2	195.5
Pentad×Marquis, III–34–1×F_1, (III–34–1×Hope)	1935	2	41.8
Pentad×Marquis, III–34–1×H44, F_2	1935	2	335.3
Pentad×Marquis, III–34–1×F_1, (III–34–1×H44)	1935	2	36.5

SUMMARY

1. Crosses were made of Marquis×H44, III–31–7, and Pentad×Marquis, III–34–1, with Minn. Double Cross, II–21–80, Hope, and H44 to study the inheritance of reaction to stem rust and black chaff.

2. Resistance to stem rust appeared to be dominant to semi-resistance.

3. The data indicated that Marquis×H44, III–31–7 carries a single dominant gene which is allelomorphic to that carried by Hope and H44 and that Minn. Double Cross, II–21–80 carries two complementary factors for semi-resistance similar to those carried by Pentad×Marquis, III–34–1.

4. Susceptibility to black chaff appeared to be dominant to resistance.

5. Resistance to stem rust was associated with susceptibility to black chaff, but the association was not complete; however, no single plant was found that was susceptible to both diseases.

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RESISTANCE OF CORN SEEDLINGS TO HIGH TEMPERATURES IN LABORATORY TESTS[1]

E. G. HEYNE AND H. H. LAUDE[2]

HIGH temperature is a major factor in limiting crop production in semi-arid regions of the United States. These regions have been subjected periodically to droughts, and in severe years complete crop failures have resulted. Weather records indicate that such seasons may be expected to recur. The resistance to high temperature and deficient moisture is an important factor to consider in the development of new varieties for semi-arid regions.

Crops that are generally grown in the semi-arid regions probably have factors that contribute to the ability of the plants to endure high temperatures and deficient moisture. High temperatures are closely associated with a deficiency of moisture in Kansas, and corn adapted to Kansas conditions probably has factors for resistance to both high temperatures and deficiency of soil moisture.

Seasonal conditions fluctuate widely from year to year in the Great Plains area. Since drought and extremely high temperatures do not occur every year, controlled laboratory equipment in which natural conditions can be simulated is an important aid in plant research.

Several investigators have shown the possibility of using controlled high temperatures to distinguish species or strains of plants that are most likely to succeed under natural drought conditions.

This paper reports a study of the effect of several factors on seedling heat susceptibility and gives a comparison of the relative drought tolerance of inbred lines of corn in the field with the seedling behavior of the same inbred lines under controlled conditions in a heat chamber.

MATERIALS AND METHODS

In the summer of 1936, when a severe drought occurred in Kansas, detailed notes were taken on the drought reaction of the strains of corn in the breeding nursery at Manhattan. The strains were classified as resistant, intermediate, and susceptible to drought. Many of these strains were later tested under controlled high temperature conditions to compare with the field behavior.

Before attempting a detailed study of differences between varieties and strains, several experiments were conducted to determine the best conditions and methods for testing corn seedlings.

The room in which the plants were subjected to heat was 5 x 5 x 8 feet. The temperature and humidity were controlled automatically. A constant circulation of air was maintained. The room was dark but could be lighted if desired. The corn was planted in 4-inch, unglazed clay pots containing a uniform soil mixture.

[1]Joint contribution from the Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kans. and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Contribution No. 295 from the Department of Agronomy. Received for publication December 2, 1939.

[2]Junior Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture; and Agronomist, Kansas Agricultural Experiment Station, respectively. The authors are indebted to Dr. A. M. Brunson for strains of corn used in making these studies.

Enough seed was planted in each pot to insure a uniform stand of seven plants per pot. Sixty-four 4-inch clay pots of corn could be tested at one time and these pots placed on a slatted table. Four or more pots of each strain were distributed at random in the heat room for each test.

Plant height and number of plants per pot were recorded before the treatment. The amount of injury caused by the treatment was estimated the third day after the test and was expressed as the percentage of exposed leaf and sheath tissue that had been killed. The tenth day after treatment the number of plants killed was recorded and notes were taken as to the degree of recovery of the remaining plants.

EXPERIMENTAL RESULTS

AGE OF SEEDLINGS

Hunter, Laude, and Brunson (3)[3] tested 14-day-old corn seedlings at 140° F for 5 hours and obtained differential injury between strains of corn. These same strains were subjected to similar conditions in the present experiment but when the plants were 20 days old. These 20-day-old seedlings were so severely injured that nearly all the plants of the strains tested died.

The greater injury to the older plants suggested that the age of the seedling may have some effect upon the ability of the plant to withstand high temperatures. To study this question, corn planted at 2-day intervals was tested when the plants ranged from 10 to 28 days old. The plants of various ages were all treated at the same time. Representative plants ranging from 12 to 22 days old at the time of treatment are shown in Fig. 1. The 10-day-old plants were very

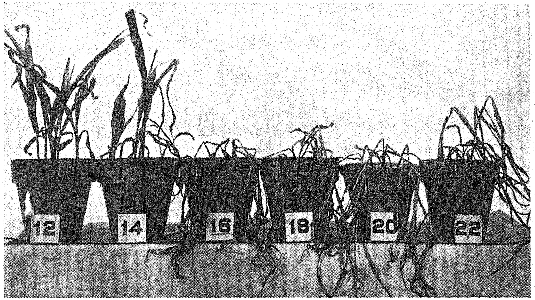

FIG. 1.—Heat tolerance of corn seedlings at different ages. The numbers refer to the age of the seedlings in days from planting to treatment. All plants were subjected to high temperature at the same time.

resistant and those 14 days old were only slightly less resistant to heat. Plants 16 to 20 days old were very susceptible. After 22 days resistance was somewhat greater as shown by the smaller percentage

[3]Figures in parenthesis refer to "Literature Cited", p. 126.

of dead plants, and it increased slightly thereafter with age. In Fig. 2 the percentage of dead plants and injury are shown graphically for plants ranging from 10 to 26 days old. The older plants were at some disadvantage because of the small size of the pots. In all the strains tested the 10- to 12-day-old plants were more resistant to heat than those 16 to 20 days old.

A study was made of the stored food reserves in the seed at intervals after planting to learn whether the amount of reserves remaining might be associated with heat resistance at different ages. Thirty kernels were weighed and planted at intervals of 2 days in large pots filled with sand. When the age of the plants in these pots ranged from

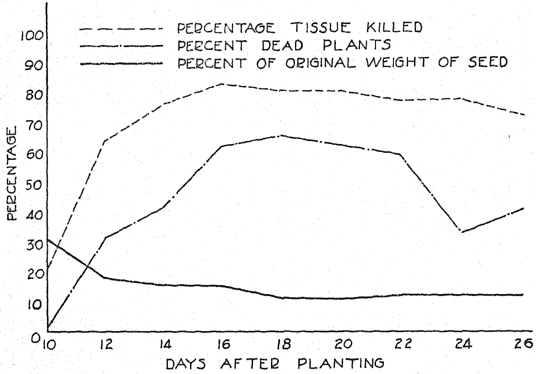

FIG. 2.—Heat tolerance of corn seedlings at different ages as indicated by percentage of dead plants and injured plant tissue. The percentage of the original weight of seeds is also shown.

10 to 28 days, the seed was carefully removed from 20 plants in each pot. The dry weight of the material that remained in the seed is shown graphically in Fig. 2. The decline in weight of seeds was apparently rapid during the first 10 days after planting, as the remaining seed was only 32% of the original weight at that time. From the twelfth to the twenty-eighth day the decline was slight. During the later period the seeds were badly decomposed and were difficult to separate from the soil.

Another study of stored food reserves was made with three strains of corn planted in sand and kept in the dark. The young seedlings were decapitated above the growing point just before the plumule broke through the coleoptile. This process was repeated every day on which one-fourth inch or more growth had occurred. The number of shoots cut off each day was recorded and the percentage was calculated on the basis of the total number of seedlings which germinated.

The results are shown graphically in Fig. 3. There was some fluctuation among the strains in percentage of seedlings decapitated, but after the thirteenth day in two strains and the fourteenth day in the third, the number decapitated daily decreased rapidly. The seedlings of the moderately resistant strain, Hy×R4, failed to send out new growth 18 days after planting. The resistant strain, PS10, grew 1 day longer; the susceptible strain, su51, grew 2 days longer. The resistant strain exhausted the reserve material in the seed at about the same time as the other two strains. Between the tenth and the fourteenth day the plants had apparently used most of the available nutrients in the seed. Soon after this period the plant would be inde-

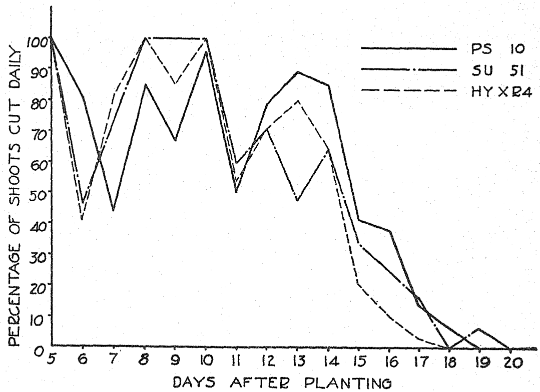

FIG. 3.—Ability of decapitated corn seedlings to send out new growth when grown in the dark. The new shoots were cut back whenever one-fourth inch or more new growth occurred. Three strains of corn were used which differed in heat tolerance.

pendent of the seed for its source of carbohydrates, and probably the available starches and sugars would be at a low level.

Miller (5), in a physiological study of the germination of sunflower seed, found that when the seedling was about 13 days old, it had exhausted all of the nutrients from the seed. When the plants were kept in air free of carbon dioxide for 7 days before this 13-day stage, he noted that several days prior to the end of this period the plants had shown no further growth of their parts.

Suneson and Peltier (6), working with winter wheat plants of various stages of development, found that young wheat seedlings that were presumably still dependent upon the endosperm to a considerable degree surpassed all other more advanced stage-of-development groups in cold tolerance. The present tests with corn have indi-

cated that 20-day-old seedlings of any strain were no longer dependent upon material in the endosperm.

Twenty-day-old corn plants subjected to heat for 5 hours at 130° F and relative humidity ranging from 20 to 30% gave the most satisfactory results for classifying relative high temperature tolerance of different strains of corn. If a longer treatment was given, variations occurred in the rate at which the pots dried during the test. Even though rather large and vigorous plants were tested, it was not necessary to add water during a 5-hour test, provided the pots were well watered before treating.

Although strains of corn vary in kernel size, there was no correlation between small kernel size and heat resistance or susceptibility. Inbred lines of corn often have a small kernel, but some of these small-kerneled strains were more resistant than the larger-seeded varieties and hybrids.

REACTION TO LIGHT

It has long been known that varying exposure to light markedly affects the growth and physiological response of a plant. When corn seedlings were treated early in the morning before they had received any daylight, they were noticeably more susceptible to heat than plants treated in the afternoon under similar conditions. A preliminary note on these and other tests has been published by Laude (4).

On observing this difference in reaction to light, two experiments were set up for a quantitative study of the relation between exposure to light and heat tolerance. In one study, the plants were exposed to various hours of daylight preceded by a period of darkness before being placed in the high temperature room. A series of plants receiving the following combinations of light and dark periods was tested:

Class 0—19 hours darkness; no light.
Class 1—18 hours darkness followed by 1 hour daylight.
Class 2—17 hours darkness followed by 2 hours daylight.
Class 3—16 hours darkness followed by 3 hours daylight.
Class 4—15 hours darkness followed by 4 hours daylight.
Class 5—14 hours darkness followed by 5 hours daylight.
Class 6—13 hours darkness followed by 6 hours daylight.
Class 7—12 hours darkness followed by 7 hours daylight.

Striking differences in heat tolerance were obtained as shown in Fig. 4. The effect of light is shown on two strains, one moderately resistant and the other resistant to heat. The complete series is not shown as there was no significant difference between classes 3 to 7 when Hy×R4 was used and no difference between classes 1 to 7 when PS10 was used. One hour of light, following 12 to 18 hours of darkness, was long enough for the corn plants to acquire considerable resistance to heat. In some cases an increase in resistance to heat was observed when the plants were exposed to light for less than 1 hour following 12 hours of darkness.

To study the rate of loss of heat resistance gained by corn seedlings that were subjected to light, the plants were exposed to various hours of daylight followed by a period of darkness before being placed in

the high temperature room. The plants were in darkness 12 hours before they received any light. The tests to study this question were arranged as follows:

Class 0—19 hours of darkness.
Class 1—12 hours darkness, 1 hour daylight, and 6 hours darkness.
Class 2—12 hours darkness, 2 hours daylight, and 5 hours darkness.
Class 3—12 hours darkness, 3 hours daylight, and 4 hours darkness.
Class 4—12 hours darkness, 4 hours daylight, and 3 hours darkness.
Class 5—12 hours darkness, 5 hours daylight, and 2 hours darkness.
Class 6—12 hours darkness, 6 hours daylight, and 1 hour darkness.
Class 7—12 hours darkness, 7 hours daylight.

FIG. 4.—Effect of light on the heat tolerance of corn seedlings receiving different periods of light and darkness. The four pots to the left are plants of Hy×R4 receiving 0, 1, 3, and 7 hours of light, respectively, and the three pots to the right are plants of PS10 receiving 0, 1, and 7 hours of light, respectively. All plants are of the same age and were treated at the same time.

These classes were subjected to high temperature at the same time so that the conditions of heat and humidity were identical for all the plants tested. Fig. 5 shows that plants which received no light were the most susceptible to heat. Other strains reacted the same as PS10, the strain shown in the illustration, except that strains susceptible to heat did not show as rapid a response to light as the resistant strains. The loss of heat resistance in plants when exposed to darkness, after receiving light, was slower than the gain of resistance in the presence of light.

This quick response to light may have a direct relation to the photosynthetic process which is dependent upon light. Dexter (1) has shown that light has a profound influence on hardening winter wheat plants against cold. Plants deprived of carbon dioxide would not harden under any circumstances, which shows that photosynthesis is involved in hardening plants. He concluded that the development

and maintenance of a high available carbohydrate supply, with retarded vegetative growth, is essential before cold-temperature reaction of hardening of plants will occur in an efficient manner. Tysdal (7) observed that light was an important factor in the cold-hardening process of alfalfa. Plants exposed 16 hours in the hardening room and to 8 hours in a warm greenhouse during daylight developed more hardiness than did those subjected to continuous temperatures. Duggar (2), in reviewing the effects of light intensity upon seed plants, stated that work had been done which indicated that plants developed in the shade are less resistant to drought than those grown in full sunlight.

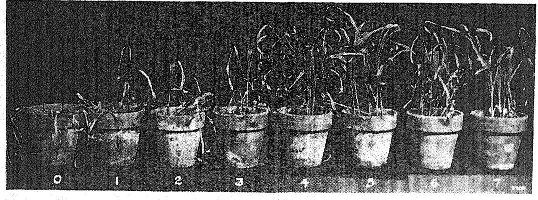

FIG. 5.—Effect of light on the tolerance to high temperatures of corn seedlings in which the plants received various periods of light followed by darkness. The numbers refer to the class combinations of light and dark periods.

OBSERVATIONS ON INBRED LINES

Approximately 50 inbred lines of corn were tested for tolerance to controlled high temperature. The field reaction of most of the lines was known from their behavior in the drought of 1936. Only a few lines were classed as highly drought-resistant in the field. Most of the lines were classed as intermediate, and it was difficult to rank them accurately as to drought resistance. A few were classed as non-drought-resistant. The latter class was small because of previous elimination during dry, hot years in Kansas.

In order to determine differential response of corn seedlings to controlled high temperatures and humidity it is necessary to subject all seedlings to the same conditions preceding the test. Differences between varieties, lines, and hybrids were the most consistent when 18- to 20-day-old plants were tested for 5 hours at a temperature of 130° F and a relative humidity of 25 to 27%. The plants were supplied with sufficient water prior to the tests to keep the soil moist throughout the 5-hour period.

Although the amount of injury varied with each test, the rank of the lines with respect to injury remained nearly constant. PS10 was included in all tests, making it possible to compare lines in the different tests. Only a few strains were highly resistant in the high temperature tests, the greater portion being intermediate in resistance to heat. These results agreed closely with the observations made in the field.

The inbred lines apparently became subject to damage by heat at definite temperatures. Some lines when subjected to temperatures of 120° F were resistant but were susceptible to slightly higher temperatures. The leaves began to curl on some lines 15 minutes after the test was started, while in others no apparent injury was observed until near the end of the test, when they became severely injured in a short time. A few lines showed dried leaf tissue within one-half hour after the test was started, but after this first brief period of susceptibility they remained unchanged during the remainder of the test. This sensitivity to small temperature changes was observed in the field in 1937. Two lines susceptible to burning of the top leaves were injured by the hot weather. The leaves of most of the plants in one line curled during midday, and, when the temperature increased to 110° F, the top leaves were killed. When the temperature was as high as 112° F, the second line was injured. In both lines the top three leaves were killed, but the plants were still in a vigorous growing condition and recovered when a 2-inch rain occurred several days later. This injury was visible throughout the season.

The reaction of mature corn in the field to drought and of seedlings tested under controlled high temperatures is shown in Table 1. The data include observations made in the field and an average of four laboratory tests with seedlings of 11 strains. All strains were subjected to heat at the same time. This group represents a wide range of inbred types as to time of maturity, height, color of grain, ear type, disease reaction, and years of self-pollination. The first four strains are white. Pride of Saline is an open-pollinated, white corn that is well adapted in Kansas. The YS strains and Mid 1 are yellow and BS 1 is an inbred line selected from Blue Squaw flour corn.

TABLE 1.—*Reaction of strains of corn to drought in the field and to controlled high temperature.*

Strain	Mature plants in field, 1936		Seedling plants under controlled high temperature		
	Drought behavior	Maturity	% injury	% dead	Recovery notes
PS10	Very good	Medium	44	0	Rapid
PS11	Poor	Early	100	70	Slow
PS55	Fair	Medium	97	38	Good
Pride of Saline	Fair	Late	68	20	Rapid
YS148	Very good	Late	58	9	Rapid
YS151	Poor, top-fire	Early	88	14	Rapid
YS164	Poor	Late	100	59	Slow
YS166	Fair	Medium	78	8	Rapid
YS174	Good	Late	95	70	Very slow
Mid 1	Good	Late	81	7	Rapid
BS 1	Escape	Very early	91	38	Slow

The strain YS174 is the only one which under controlled conditions did not react as expected from the field behavior to drought. This inbred occurred in the best single crosses in 1935 with respect to drought resistance. A possible explanation for the high injury of the seedlings

of YS174 from heat may be its aberrant seedling growth. The seedlings of this line have yellow striations on the leaves, which may be a type of chlorophyll deficiency. The rate of growth is slow until it becomes about 18 inches high, and at this time it becomes a uniform green color and begins to grow vigorously.

PS10 and YS148 were considered to be the best inbreds in drought reaction in the field and they also were the best when subjected as seedlings to high temperature. PS55 does not appear to be desirable from the data obtained on seedlings under controlled conditions, but it does have a fairly good field record.

The reaction of YS151 to drought in the field and laboratory is interesting. This inbred line appears to be vigorous in the field under normal growing conditions. However, when high temperatures occur, it begins to top-fire. If after two or three of the top leaves are dried by the heat moisture and cool conditions occur, this line will continue growth. If this burning occurs before the tassel has emerged and favorable weather conditions return, the plant will continue growth, shed viable pollen, and produce grain. The data in Table 1 show that YS151 had a high percentage of tissue killed but a relatively low percentage of dead plants. All the exposed leaf and sheath tissue could be burned at the time of treatment, but one week later the same plant might be growing vigorously. In this case there was a close agreement between the field behavior of older plants and behavior of seedling plants under controlled conditions.

The high temperature room may well be used to study hybrid populations that are segregating for heat tolerance. Fig. 6 shows the segregation of heat tolerance in closely related material. M2 is a resistant inbred which was crossed with a susceptible strain, T4–6a, a sugary translocation. The F_1 of this cross, which is not shown, was outcrossed to another susceptible sugary strain (third pot from left). The resulting cross gave a 50–50 segregation of starchy and sugary

FIG. 6.—Segregation for heat tolerance in cross between resistant and susceptible strains of corn. M2 is the resistant parent, T4–6a the susceptible parent; *susu* (third pot from left) is the susceptible stock to which the F_1 of the above cross was outcrossed. The four pots on the right are the segregates of the plants from starchy (*Susu*) and sugary (*susu*) kernels.

kernels. The plants labeled *Susu* came from the starchy segregates and those labeled *susu* came from the sugary segregates. All plants shown in the illustration were planted and subjected to high temperatures at the same time. The starchy segregates were more resistant to high temperatures than were the sugary segregates. A manuscript is in preparation which discusses the genetics of heat tolerance in corn.[4]

DISCUSSION

Since the corn crop is much influenced by variable weather conditions, an improvement program should be directed toward producing inbred lines and hybrids that will withstand unfavorable growing seasons.

When the growing season is favorable for corn production, little if any progress can be made in selecting strains of corn that are superior in drought resistance. The use of a high-temperature room can then supplement field studies. The reaction of about 90% of the inbred lines of corn subjected to controlled high temperatures was in accord with their known field behavior in Kansas. Only one inbred line differed widely in laboratory reaction and field reaction. All lines that appeared poor in the field were poor also in laboratory trials. Thus, by discarding on the basis of their behavior in the high temperature room, all the poor lines would have been eliminated. Most of the strains that were good in the field also were good under controlled conditions. Using the results of the high temperature room, a large percentage of the more desirable heat-resistant strains would be retained. However, it is believed that information obtained by subjecting corn seedlings to high temperatures should be used only to supplement field studies.

Some lines of corn may have many desirable characteristics but still be susceptible to dry, hot conditions. YS151, the line discussed previously, which top-fired in the field but continued to grow when favorable conditions occurred soon enough, could probably be improved by backcrossing. This line appears promising in crosses, except for top-firing, has good vigor, and produces a desirable kernel for an inbred. It might be improved by crossing with a drought-resistant line and through several generations of back-crossing the susceptible types probably could be eliminated by subjecting seedlings to a high temperature test.

SUMMARY

The reaction of corn seedlings to artificial heat was studied and this reaction was found to correlate well with the behavior of the same strains under field conditions. Seedlings 10 to 14 days old treated for 5 hours at 130° F, with a relative humidity of 25 to 30%, were more heat tolerant than those at the later stages of early development.

Decapitation experiments and decline in weight of seeds indicate that after the fourteenth day the young plants had exhausted most of the food material from the endosperm.

[4]Association between drought resistant factors and certain linkage groups in maize. E. G. Heyne and A. M. Brunson.

The heat resistance of corn seedlings kept in the dark for 12 to 18 hours was increased considerably by exposure to light for as short a period as 1 hour.

The results indicate that the testing of seedlings for heat resistance can be relied upon with considerable assurance for distinguishing genetic differences in the drought tolerance of larger plants of different strains of maize.

A high temperature test apparently is a valuable supplement to field studies of drought resistance.

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GENETIC STUDIES OF RESISTANCE TO ALFALFA MOSAIC VIRUS AND OF STRINGINESS IN *PHASEOLUS VULGARIS*[1]

B. L. WADE AND W. J. ZAUMEYER[2]

THE investigations included in this paper deal with the genetic results obtained with a cross of bean varieties in which reaction to an alfalfa mosaic virus and stringiness were studied. It has been shown by Zaumeyer and Wade (6)[3] that varieties of beans may be designated as resistant or susceptible to an alfalfa mosaic virus, which was later designated as alfalfa virus 1 (7).

Various genetic studies of stringiness have been completed in which simple and more complicated explanations have been used. A single factor difference with stringless dominant over stringy was found by Emerson (2) and by Wellensiek (5), while a segregation in the F_2 of 15 stringless to 1 stringy was found by Prakken (4). On the other hand, there was some evidence for the dominance of stringiness over stringlessness found by Currence (1), Emerson (2), and Joosten (3). Currence (1) reported two types of stringiness, one in which stringiness was due to two dominant complementary genes, and the other in which an incompletely dominant gene for stringlessness was accompanied by an inhibiting factor. Joosten (3) distinguished ten classes of stringiness.

MATERIAL AND METHODS

The crosses involved were of pure lines of Corbett Refugee designated as Mosaic Resistant Refugee Rogue and of Idaho No. 1 Mosaic-Resistant Great Northern. The F_1 of these crosses was very prolific so that all F_2 seed used came from two plants; the A strain, in which the Mosaic Resistant Refugee Rogue was used as the female parent; and the B strain, in which Idaho No. 1 Mosaic Resistant Great Northern was used as the female parent. In order to simplify the designations, these parents are hereafter referred to as Refugee Rogue and Great Northern.

The Refugee Rogue strain used is resistant to alfalfa mosaic virus 1 under conditions prevailing during the tests at Charleston, S. C., and is stringless. Under the same conditions the strain of Great Northern used is susceptible to the virus and is stringy.

The virus used was taken originally from alfalfa, inoculated to peas (*Pisum sativum* L. var. Laxton Progress), then to petunia (*Petunia hybrida* Vilm.) Inoculations in the spring were made from a mixture of about 5% expressed juice from alfalfa and 95% from peas, but inoculations in the fall were made from a mixture of about 5% expressed juice from alfalfa, 15% from peas, and 80% from petunia.

The F_1 from these crosses were not inoculated with alfalfa mosaic virus and notes were not made on stringiness. The F_2 and parents were planted at Charleston, S. C., in the spring of 1938 and inoculated on the seventh day after emergence.

[1]Contribution from the Division of Fruit and Vegetable crops and diseases, U. S. Dept. of Agriculture. Received for publication December 4, 1939.
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[3]Figures in parenthesis refer to "Literature Cited", p. 134.

A fine pumice stone powder was sprinkled on the primary leaves and a block exactly 1 inch square was held under the leaf while the upper surface immediately over the block was rubbed with a cloth saturated in juices from alfalfa-mosaic-virus infested plants. In order to have results as comparable as possible, all inoculating was done by one person and an attempt was made to apply a fairly uniform light pressure to an area of approximately 1 square inch.

The F_3, parents, and a small remnant of F_2 were planted at Charleston, S. C., in the fall of 1938 and inoculations made as before, except that one other worker was necessary in order to cover the material quickly.

The number of local lesions per inoculated leaf was recorded for each plant one week after inoculation. Stringiness was designated by letters, A indicating strong string, B medium, C weak, D trace, and E none.

RESULTS

In order to determine the best method of inoculation, 50 plants of Great Northern were inoculated using approximately 25 grams pressure, and the same numbers at 50 and 75 grams, respectively. The light pressure gave an average of 10.1 ± 0.81 local lesions; the medium pressure 12.2 ± 0.53 lesions; and the heavy pressure, 10.4 ± 0.92 lesions. It was therefore decided to use the medium pressure, although the differences involved were not statistically significant.

Due to a severe frost it was impossible to obtain any seed from the progenies grown in the fall of 1938 and several were killed before they had attained sufficient development of pods to determine whether or not they were stringy or stringless.

INHERITANCE OF RESISTANCE TO ALFALFA MOSAIC VIRUS

Table 1 shows a summary of the results obtained in F_2 and F_3 from plants inoculated with alfalfa mosaic virus 1. From a total of 444 F_2 plants examined, 20 were found to be infected and 424 healthy. On the basis of an expected 15 resistant to 1 susceptible, $X^2 = 3.114$, there was a non-significant deviation. In the F_3, 79 progenies segregating in 15:1 ratios gave a total of 2,344 resistant to 145 susceptible with $X^2 = 0.765$. If these F_2 and F_3 ratios are added together, a ratio of 2,768:165, $X^2 = 1.951$ is obtained.

The F_3 families themselves furnish additional evidence in favor of the 15:1 hypothesis. One hundred thirty F_3 families were found to be entirely free from lesions of the alfalfa mosaic virus, while 79 gave 15:1 ratios, 79 gave 3:1 ratios and 15 were fully susceptible to the virus. The X^2 value for 303 families with 3 degrees of freedom is 0.976, based on a 7:4:4:1 expectation.

The 79 families segregating in ratios of 3 resistant to 1 susceptible gave a total of 1,554 resistant to 474 susceptible plants, with $X^2 = 2.864$.

Table 1 further shows that there are no significant differences between the cross and its reciprocal insofar as reaction to alfalfa mosaic virus is concerned.

The alfalfa-mosaic resistant parent planted at regular intervals throughout the plots remained free from lesions while in all cases the susceptible parent showed lesions.

TABLE 1.—*Results obtained with F_2 and F_3 progenies from the cross (A) Mosaic Resistant Refugee Rogue×Idaho No. 1 Mosaic Resistant Great Northern and (B) reciprocal, when inoculated with alfalfa mosaic virus 1.*

F_2 generation

When grown*	Resistant plants	Susceptible plants	X^2†
A Strain			
S	155	8	0.501
F	79	3	0.940
B Strain			
S	157	7	1.099
F	33	2	0.017
Total	424	20	3.114

F_3 generation families

When grown*	Resistant plants	15:1	3:1	Susceptible plants	X^2	D.F.‡
A Strain						
F	60	42	39	8	1.175	3
—	—	—	—	—	—	—
B Strain						
F	70	37	40	7	1.098	3
—	—	—	—	—	—	—
Total	130	79	79	15	0.976	3

F_3 segregating progenies

Strain	No. families	When grown*	X^2§	D.F.	No. resistant plants	No. susceptible plants	X^2
15 resistant: 1 susceptible							
A	42	F	8.655	42	1,134	70	0.391
B	37	F	12.425	37	1,210	75	0.375
Total	79		21.080	79	2,344	145	0.765
3 resistant: 1 susceptible							
A	39	F	19.464	39	764	230	1.071
B	40	F	8.899	40	808	244	1.830
Total	79		28.363	79	1,554	474	2.864

*S indicates spring grown; F fall grown.
†None of the above X^2 values exceed the 5% point.
‡When degrees of freedom (D.F.) are 1 for a given ratio, they have been omitted.
§X^2 added from individual progenies with 1 degree of freedom for each progeny.

INHERITANCE OF STRINGINESS

Table 2 shows a summary of the results obtained in F_2 and F_3 when stringiness was studied. Two hundred eleven F_2 plants were stringless and 150 stringy, X^2 equals 0.709 based on a 9:7 ratio. In arriving at stringiness and stringlessness it was found that A, B, and C types should be classed as stringy and D and E as stringless. This was borne out by F_3 results. In the F_3, 59 progenies segregating in 9:7 ratios gave a total of 693 stringless to 535 stringy: X^2 equals 0.015. When the F_2 and F_3 plants, for 9:7 ratios are added, the ratio becomes 904:685, and X^2 equals 0.261.

On the basis of an expectation of 1 stringless, 4 segregating 3 stringless to 1 stringy, 4 segregating 9 stringless to 7 stringy, and 7 stringy families in F_3, a X^2 of 7.720 for 3 degrees of freedom was obtained. However, when this X^2 was corrected for continuity the value was reduced to 6.895. The observed values are 26:69:59:103 F_3 families.

The 69 families giving a ratio of 3 stringless to 1 stringy in F_3 gave an actual ratio of 1,026:306, and X^2 equals 2.919.

Table 2 shows that there is no significant difference between reciprocal crosses insofar as stringiness is concerned.

LINKAGE STUDIES

Table 3 shows the results obtained when F_3 X^2 values for linkage were computed for resistance to alfalfa mosaic virus and stringiness. In no case did the value obtained indicate that the 5% point of probability was exceeded.

Linkage determinations based upon the combined F_2 from the cross and its reciprocal gave a linkage X^2 value of 0.302 based on frequencies of 198 healthy stringless: 13 virus infected stringless: 143 healthy stringy: 7 virus infected, stringy. X^2 for the cross (A) was 1.076, for the reciprocal (B) 0.069.

On the basis of these observations it is concluded that there is no evidence of linkage between any of the four pairs of factors involved in the expression of these characters. Chi square for the combinations of ratios used indicated that no exceptionally variable ratios were encountered (last two columns Table 3).

DISCUSSION

The results obtained in this study of the genetics of alfalfa mosaic virus are fully in accord with the original study of Zaumeyer and Wade (6) in which it was found that Great Northern was susceptible to alfalfa mosaic virus while Corbett Refugee was resistant. However, there is an apparent discrepancy between these results and those reported later by Zaumeyer (7), in which both varieties were found to be moderately susceptible to alfalfa mosaic virus 1. It seems worth while to point out that there is considerable difference in the technics and strains used for an analytical genetic study compared to those used in a variety test of host range in a pathological study. It is probable that in the following possible explanations there may be found the reason for the apparent conflict with the later publication (7):

TABLE 2.—*Results obtained with F_2 and F_3 progenies from the cross (A) Mosaic Resistant Refugee Rogue × Idaho No. 1 Mosaic Resistant Great Northern and (B) reciprocal Classified in stringless and stringy classes.*

F_2 generation

When grown*	No. plants stringless	No. plants stringy	X^2†
A Strain			
S	92	71	0.221
F	12	6	0.794
B Strain			
S	96	68	0.348
F	11	5	1.702
Total	211	150	0.709

F_3 generation families

When grown*	Stringless	3 stringless: 1 stringy	9 stringless: 7 stringy	Stringy	X^2	D.F.‡
A Strain						
F	13	27	26	49	5.104	3
—	—	—	—	—	—	—
B Strain						
F	13	42	33	54	4.346	3
—	—	—	—	—	—	—
Total	26	69	59	103	7.720	3

F_3 segregating progenies

Strain	No. families	When grown*	X^2§	D.F.	No. stringless plants	No. stringy plants	X^2
9 stringless: 7 stringy							
A	26	F	17.584	26	299	222	0.275
B	33	F	22.136	33	394	313	0.083
Total	59	F	39.720	59	693	535	0.015
3 stringless: 1 stringy							
A	27	F	14.168	27	487	145	1.426
B	42	F	8.278	42	539	161	1.493
Total	69	F	22.446	69	1,026	306	2.916

*S indicates spring grown; F fall grown.
†None of the above X^2 values exceed the 5% point.
‡When degrees of freedom (D.F.) are 1 for a given ratio, they have been omitted.
§X^2 added from individual progenies with 1 degree of freedom for each progeny.

TABLE 3.—*Chi square values for determination of association or linkage between ratios obtained from F_3 segregating progenies for resistance to alfalfa mosaic virus 1 and stringlessness, from the cross (A) Mosaic Resistant Refugee Rogue×Idaho No. 1 Mosaic Resistant Great Northern and (B) reciprocal.*

Cross	Number of plants: Alfalfa-virus resistant Stringless	Alfalfa-virus susceptible Stringless	Alfalfa-virus resistant Stringy	Alfalfa-virus susceptible Stringy	Ratios*	Association or linkage X^2†	D.F.	Linkage X^2 added from individual progenies	D.F.	Linkage X^2 differences	D.F.
A	137	8	103	7	15:1 and 9:7	0.078	1	11.416	10	11.338	9
B	92	4	81	3		0.059	1	12.097	10	12.038	9
Total	229	12	184	10		0.003	1	23.513	20	23.510	19
A	90	3	18	2	15:1 and 3:1	1.290	1	7.076	5	5.786	4
B	95	8	26	3		0.172	1	12.181	7	12.009	6
Total	185	11	44	5		1.158	1	19.257	12	18.099	11
A	46	7	31	9	3:1 and 9:7	1.099	1	3.257	5	2.158	4
B	14	5	14	2		0.943	1	3.484	4	2.541	3
Total	60	12	45	11		0.149	1	6.741	9	6.592	8
A	127	35	41	13	3:1 and 3:1	0.132	1	3.522	6	3.390	5
B	140	53	50	12		1.621	1	15.412	15	13.791	14
Total	267	88	91	25		0.478	1	18.934	21	18.456	20

*In each case the ratio for resistance vs. susceptibility to alfalfa-mosaic virus is given first, followed by the ratio of stringlessness vs. stringy.
†None of the above X^2 values exceed the 5% point.

1. In dealing with Corbett Refugee originally (6, 7) no effort was made to use pure lines, while in the study reported here only two single parent plants were involved. It is quite possible that a single plant picked out of a variety may have some characteristics different from the mean of that line. The number of plants tested in previous studies have been small so that the results reported cannot be expected to be rigidly applicable to large numbers of plants in a pure line selected from the original parent strain. As a matter of fact, in the original study (6) there was an indication that the Great Northern was heterogeneous for susceptibility and resistance since only 3 out of 10 were infected. The different results reported for Corbett Refugee (6, 7) may merely indicate heterogeneity. The results are presented in a different way in the later publication (7), but the total lesions for 10 plants inoculated in each case with three strains of alfalfa mosaic virus 1 we find that 30 Corbett Refugee plants produced 343 lesions while the same number of Great Northern plants produced 778 lesions. This is an average of 11.43 and 25.93 lesions, respectively. At Charleston the best technic for the Great Northern gave an average of 12.2 lesions, or a reduction of 13.73 lesions per plant. If the same absolute reduction held true for the Corbett Refugee, assuming a mixture of the three types of alfalfa mosaic virus, then that variety would be expected to be resistant under Charleston conditions.

2. In previous studies (6, 7) the inoculum used was taken from alfalfa plants infected with alfalfa mosaic virus 1, while in this study only a small portion of alfalfa juice was used. The possible influence of the other plant juices on infection may have to be taken into consideration.

3. Pure lines of the alfalfa mosaic virus 1 are not available and each time a study has been made of it new collections from alfalfa have been made. Slight changes in the virus may result in a considerable change in the ability of the virus to infect various host strains and varieties.

4. In pathological studies of the virus (6, 7) no abrasive was used in the inoculations while in this study finely ground pumice stone was used. The application of virus to thousands of plants must necessarily be done in a quick and dependable way if results are to be comparable. The development of such a technic may result in a change in level of infectivity of the virus, whereby two varieties that are susceptible by a leisurely technic may be differentiated by the large scale method.

5. No adequate studies of the effect of various environments on alfalfa mosaic virus 1 have been made, so that some of the differences encountered may be due to the influence of the environment on the virus, host plants or both. At Charleston the individual local lesions were relatively smaller than those produced near Washington, D. C., there was practically no tendency for coalescence to occur, and the number of lesions per susceptible plant was low.

From work previously done by other investigators (1, 2, 3, 4, 5), it could very well be expected that additional genetic ratios for stringiness vs. stringlessness might be found.

SUMMARY AND CONCLUSIONS

In a cross between strains of Corbett Refugee (Mosaic Resistant Refugee Rogue shortened to Refugee Rogue) and Idaho No. 1 Mosaic Resistant Great Northern (designated here Great Northern) and reciprocal, inheritance of resistance to alfalfa mosaic virus 1 and stringiness of pods were studied.

Genetic observations were made in F_2 and F_3 for both characters. From over 400 F_2 plants and over 300 F_3 families (about equally divided between the cross and its reciprocal), it was concluded that resistance is due in this case to duplicate dominant genes giving a ratio of 15 resistant to 1 susceptible in F_2; and a ratio of 7 resistant to 4 segregating 3:1, to 4 segregating 15:1, to 1 susceptible families in F_3. The statistical constants computed indicated no reason for questioning this hypothesis.

The same plants used in the virus study were classified for stringiness, except that frost destroyed part before they were sufficiently mature for classification. It was found that stringiness in this cross is due to duplicate recessive genes in which the dominant alleles are complementary. Satisfactory fits to a ratio of 9 stringless to 7 stringy were found in F_2; and to a ratio of 1 stringless family, to 4 segregating 3 stringless to 1 stringy, to 4 segregating 9 stringless to 7 stringy, to 7 stringy in F_3.

No linkage or association was found between stringlessness and resistance to alfalfa mosaic virus 1.

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AGRONOMIC RESEARCH PROJECTS[1]

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RESEARCH in agronomic fields embracing crop improvement and production, soils, and fertilizers has long occupied a leading position in the programs of the state experiment stations and has composed a substantial part of the activities of the U. S. Dept. of Agriculture. Experimentation in the pioneer years of the experiment stations, made largely in response to local requests for information on immediate practical problems, including for example, variety, cultural, rotation, and fertilizer tests and breeding work with many crops, was usually elementary in nature and of conventional type. The subjects dealt with often appeared simple and possible of solution by a few comparative tests. Many of the problems, however, were more involved than was apparent upon first consideration, and new methods and improved technic were needed for their solution.

During recent years, experiment station agronomists have been giving special attention to more complex and more fundamental problems, such as weather-crop relations; soil-fertility problems associated closely with crop production and plant composition; availability of essential soil nutrients to the plant, effects of their deficiencies, and effective and economical methods of supplying them to crops in fertilizers; vegetative and other methods of soil-erosion control; machine-harvesting problems; crop storage and handling; and factors variously affecting market values and qualities of the several crops. Prominent in present-day agronomic research is the improvement of cereal, fiber, oil-seed, forage, sugar, and root crops and tobacco in yield, resistance to diseases, insects, and adverse environmental factors, and in market and technological qualities. Work in this field usually proceeds in association with research in genetics and cytology. Agronomic phases of the greatly expanded pasture investigations throughout the country are also receiving serious attention.

Many of these problems go far beyond the province of a single institution and have been best coped with by cooperative action among several or many stations and the U. S. Dept. of Agriculture. These broader activities find places in the station programs along with the more fundamental researches that provide information on which to base experimentation with more immediate practical application, and the numerous variety, fertilizer, cultural, and harvesting tests, often more or less conventional or local, yet necessary in the broad industry of agriculture.

RESEARCH ON A PROJECT BASIS

Most of the research in agronomy, as in other fields of agricultural science dealt with by the experiment stations and the U. S. Dept.

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of Agriculture, is on a project basis. This is particularly true for all work financed by allotments from appropriations authorized under the Adams, Purnell, and Bankhead-Jones Acts at the stations and the lines of work proceeding in cooperation with divisions of the Department and other governmental agencies. The formal project as the basis for research and allotment of funds was accepted by general agreement soon after the passage of the Adams Act in 1906.

The research programs of the experiment stations, financed from all sources, have included during the last two or three years approximately 8,500 projects embracing a wide range of agricultural and rural-life problems. About 3,020 of these projects with approved written outlines were supported during the fiscal year 1938–39 by Adams, Purnell, or Bankhead-Jones funds, often with supplemental financing by Hatch and state funds, and included 587 projects in definitely agronomic subjects. These comprised 234 concerned with production of field crops, 37 with crop-plant genetics, 119 with pastures and ranges, and 197 with soils and fertilizers. In addition there were many projects in horticulture, forestry, and plant pathology of interest to agronomists because of the genetics, cultural and field practices, and soil and fertilizer problems involved.

The U. S. Dept. of Agriculture, as represented by the Office of Experiment Stations, is charged with the administration of the several federal funds allotted to the state experiment stations for research, and this has been on the basis of approved projects for the Adams, Purnell, and Bankhead-Jones funds, a procedure agreed to by the Association of Land-Grant Colleges and Universities. Consideration by the Office of Experiment Stations of projects submitted in outline for support from these three federal funds involves much more than simple approval. New projects are subjected to critical examination and analysis before being accepted. Attempt is made to insure clarity and adequacy in the outlines, to make certain that procedures reflect up-to-date developments in research, and to offer any suggestions which might prove helpful. The purpose is always to assist by suggestion and discussion, calling attention to other pertinent investigations, with a desire to encourage and preserve local initiative, and with full recognition of the responsibility of the experiment station for making final decisions.

The formal project usually originates with the leader after conference with the director of the experiment station. The project outline is one of the clearest evidences of a worker's motives, his vision, and his preparation to carry through an investigation. A good outline shows clear thinking, a definite purpose, and a well-determined course of action. Specific objectives and plans of procedure may sometimes be tentative, subject to change with the progress of an investigation but they are essential and give effective direction to the effort.

The problem which the investigation proposes to solve may have its origin in demands from local groups or agencies or in current conditions, such as climatic disturbances, outbreaks of disease or insects, labor shortage, or excess production. It may arise as an offshoot from an investigation in progress, in the recent findings of other agrono-

mists, or it may be an original concept. Slipher[3] recently has indicated considerations attending the recognition and evaluation of research problems. In conclusion he emphasizes, "(1) that skillful identification of the problem is no less a duty of research than is its solution; (2) that problems possess facial appearance, structural breadth, and depth; (3) that the more penetrating tool for exploring the problem lies in the scientific method; and (4) that practicability—though sometimes an objective—is not a method." Regardless of the origin of a problem, there are certain fundamentals which should receive attention in drawing up a research project for its solution.

Experience over three or more decades has shown that the research project is most likely to be effective when it is definite, restricted in scope to what may be accomplished in a reasonable time, and aimed at a few simple objectives; a seasoned, carefully considered enterprise, subjected to prior criticism and suggestion and formulated only after thorough consideration of the status of knowledge on the subject, including previous findings, and where possible the current work of others.

ESSENTIALS OF AN AGRONOMIC RESEARCH PROJECT

The essential points to be covered in a research project outline have been under consideration for many years by the Association of Land-Grant Colleges and Universities. It is their view[4] that "the precise and complete form and content of a project outline, applicable to all cases, would be difficult to prescribe, but adequate and definite information . . . is essential. . . . The project should be designed to undertake thoroughly and with reasonable completeness the investigation of the subject and it should not be fragmentary and superficial." It may be useful to discuss briefly the major considerations in the formulation of adequate research project outlines. The discussion is based on statements made then and modified later and amplified by the writer.

Title.—The title should be a brief, clear, specific designation of the research to be undertaken. Simple indefinite labels, such as Potato Investigations, Wheat Production, or Forage Improvement, may have the merit of brevity, but they fail to characterize the proposed investigation and should be avoided, Unnecessary words, such as "study of" or "investigation of" can well be omitted.

Objectives.—A clear statement of the specific objectives of the project is important. These should be in logical order, should not refer to procedures, and, when more than one objective is stated, they should bear an intimate relation to each other and to the major over-all objective. Some projects, e. g., Weed Investigations, Wheat Production, amount to blanket proposals. They are open to the objection that they do not state a problem but indicate a field; they offer many objectives or an indefinite composite aim.

[3]SLIPHER, J. A. How to recognize and evaluate a research problem. Agr. Eng., 20:309, 310. 1939.

[4]Report of the Committee on Experiment Station Organization and Policy. Assoc. Land-Grant Col. and Univ. Proc., 45:265, 266. 1931.

Reasons for undertaking the study.—The outline should include a statement showing the importance of the problem to agriculture or rural life, the probable use of the results, and the justification for the research under the particular funds designated for its support. U. S. D. A. Miscellaneous Publication No. 348 (June 1939) gives the texts of the several federal-grant acts and their requirements and limitations. Even for the more fundamental researches the statement should set forth the practical agricultural objective of the proposed work so clearly that any intelligent layman can readily understand and appreciate its general purpose. Such information is a requisite for administrators who often may have to explain and defend the different lines of work in progress.

Previous work and present outlook.—A brief summary should cover previous research on the problem (citing the more important publications), the status of current research, and the additional information needed to which the project is expected to contribute. Thorough knowledge of the earlier and current work on the subject of the proposed inquiry is essential in order that needless repetition or duplication of the work of others may be avoided, and also to take account of the most advanced methods. As Allen[5] pointed out 10 years ago, "A research project should start where others have left off or where apparently their work has ended. Repetition and replication may be warranted where aimless duplication is not, but blind repetition without any definite or justified reason and devoid of any new idea is a reflection on imagination and individuality."

The *Experiment Station Record* furnishes a current survey of agricultural research now extending over 50 years, and such publications as *Biological Abstracts*, *Herbage Abstracts*, *Plant Breeding Abstracts*, and *Chemical Abstracts* record progress in specialized branches of agronomic science. Useful reviews of previous work in the field of the problems under consideration often may be found in bulletins and journal articles. The *Journal* of the American Society of Agronomy and *Soil Science* are excellent reporters of results of agronomic inquiry and are useful for the exposition of improved methods of research. The annual reports of the stations usually give progress results from currently active projects. The Office of Experiment Stations endeavors to maintain a classified file of research projects under way at the experiment stations. These are but a few of the many sources of information on the results of research with crops and soils.

Procedure.—An explicit statement should indicate the essential working plans and methods to be employed in attaining each objective, the phases to be undertaken currently, and the facilities and equipment needed and available. The procedure should be adequate, well balanced, and representative of the progress and current views on methods and technic, and ought to show clearly provision for solving each objective. The details of procedure may have to be revised from time to time in line with experience and new information, in which case a new outline is advisable.

[5]ALLEN, E. W. Initiating and executing agronomic research. Jour. Amer. Soc. Agron., 22:341–348. 1930.

The determination of what data are essential, development of ways to obtain them, and tests of their applicability and significance make up a large part of agronomic research. The natural aim is to obtain relevant and positive evidence extensive enough for critical analysis. Endeavors in this direction may be defeated by all-too-frequent faults in technic, such as inclusion of too many variables, lack of proper checks or basic treatments, disregard of nonuniformity of test soils, inadequate replication, no arrangement for appropriate statistical treatment of results, and failure to consider interplat competition. Technic defective in these respects is inexcusable in agronomic investigation, especially when one considers the many sources of information now available on the subject.

Probable duration.—An estimate of the maximum time probably needed to complete the project and publish results also is of value. The period should not be unduly protracted, although long enough to attain the objectives and report on the findings. When these are accomplished the project is best amended or closed and replaced with a new enterprise. Prolonged projects without changes in plan or objectives all too often become unfruitful and hence are difficult to defend.

Financial support.—The leader should include an estimate of annual allotments (by funds) needed for (1) salaries and (2) maintenance, based on analysis of requirements for salary, labor, equipment, supplies, travel, other operating expenses, and publication. In this connection it is well to keep in mind that while the administration of the institution necessarily must practice economy and good judgment in the allotment of funds to research, inadequate support has been found wasteful and ineffective and often responsible for indifferent and protracted efforts.

Departments involved.—It is of advantage to indicate each of the departments or organized divisions of the institution contributing to the project essential services or facilities and the respective functions and responsibilities of each in the investigations. Attention to this feature will help to obviate possible future misunderstandings.

Personnel.—The leader or leaders and other technical workers assigned should always be shown. It has been found wise, where practicable, to have only one person responsible for an individual phase or study in the project. Prudent administration and assignment of personnel are essential to successful cooperation and to balanced completeness in the undertaking.

Cooperation.—A project statement should give recognition to any formal or informal cooperation involved with the bureaus of the U. S. Dept. of Agriculture or with other experiment stations or institutions and should list the effective date of any memoranda of understanding concerned. The complexity of many of the agronomic problems of today and the trend toward basic research have led agronomists to profit more and more from the experience of workers in other scientific and technical lines, and to use their methods, their findings, and their collaboration in attacking new problems or untouched or unsolved aspects of older inquiries. Many of the research plans may properly involve the functions of two, three, or even more different lines in a

combined attack. This type of cooperation is excellent so long as each participant realizes that the situation is one calling for mutual helpfulness and team play and not a scheme for evading responsibility. The rôle of each should be stated definitely. In cases where the problem and the outlook extend beyond the jurisdiction and the personnel and financial resources of one station, the situation often is best dealt with by each agency setting up a project that forms a part of a cooperative program. Examples of such cooperative efforts on an extensive scale are the national improvement programs involving cereals, fibers, sugar crops, potatoes, and tobacco; the cotton research program covering most aspects of cotton production, marketing, and utilization; and the several active pasture programs.

CONCLUSIONS

Every agronomic research project should be regarded as a joint investment of the leader, the institution, and the public. The returns from the enterprise will depend in part upon the leader, his attitude and ability, and his comprehension of the problem and its needs, and in part upon the administrator, his wise guidance and encouragement, and his ability to arrange for the facilities, operating expenses, personnel, and time essential to its successful prosecution.

RESISTANCE OF F_1 SORGHUM HYBRIDS TO THE CHINCH BUG[1]

R. G. DAHMS AND J. H. MARTIN[2]

THE differential effect of chinch bugs (*Blissus leucopterus* Say) on varieties of sorghum has been reported in detail by Snelling, *et al.* (3).[3] Most sorghum hybrids show high resistance to chinch bug injury in the F_1 generation, but heretofore it has never been possible to determine, except by extensive progeny tests, whether this resistance was genetic or merely a result of the rapid and heavy plant growth usually exhibited by sorghum hybrids. Dahms, *et al.* (1) have shown that, as a general rule, chinch bugs lay more eggs and live longer, and the nymphs develop into larger bugs, on susceptible varieties than on resistant varieties, but that these differences are less marked under field conditions than under laboratory conditions. The laboratory method of determining resistance used heretofore consists in placing a fresh seedling in each cage every day with the roots immersed in water. Such a large number of seedlings are required that studies of the inheritance of resistance have been almost precluded. With this method the production of sufficient crossed seed for the testing of F_1 hybrids is laborious and tests of the F_2 generation are impossible. This handicap has now been eliminated by the development of a method of caging known numbers of bugs on growing plants in the field. The resistance to chinch bug injury is determined by observing the effects of the host upon the development of the insects rather than the effects of the insects upon the host. The presence of factors for resistance apparently may be detected by the use of this method, which is described in this paper.

With the number of eggs laid by, and the duration of life of, chinch bugs confined to plants growing under field conditions as a criterion, the reactions of 11 hybrids in the F_1 generation were measured and certain applications of the data to the problem of breeding for resistance are suggested. Studies of the inheritance of resistance in the F_2 generation are now in progress. The experiments were conducted in 1938 at the U. S. Dry Land Field Station, Lawton, Okla.

MATERIAL AND METHODS

The cages used to confine chinch bugs on plants growing in the field (Fig. 1) consisted of a special type of celluloid tube about 7 cm long and 2.5 cm in diam-

[1]Cooperative investigations between the Oklahoma Agricultural Experiment Station and the Bureaus of Plant Industry and Entomology and Plant Quarantine of the U. S. Dept. of Agriculture. Abstract of a portion of thesis submitted by the senior author to Kansas State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of doctor of philosophy. Received for publication December 11, 1939.

[2]Assistant in Entomology and Senior Agronomist, respectively. The writers wish to express their appreciation to W. M. Osborn, superintendent of the Lawton, Okla., station of the Bureau of Plant Industry, U. S. Department of Agriculture, for providing facilities for these experiments, and to F. A. Fenton, Oklahoma Agricultural Experiment Station, and P. N. Annand and C. M. Packard, Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture, for making these experiments possible.

[3]Figures in parenthesis refer to "Literature Cited", p. 147.

eter. A cork stopper covered with muslin cloth was placed in each end of the tube. An ellipsoid hole was cut in the side about midway between the ends of the tube. This hole was covered with muslin which was glued to the celluloid with a special type of water-proof glue. Each tube was fastened crossways on one side of a sorghum stalk, with the muslin-covered hole next to the stalk, by passing a fabric-covered elastic band around the stalk and snapping it over the ends of the tube. Fabric-covered bands were necessary, as plain rubber bands soon became brittle and broke under field conditions. Bugs placed in these cages appeared to have no difficulty in feeding through the cloth. The cages were placed on the north side of sorghum plants and as much in the shade as possible. Under these conditions the temperature ordinarily ranged from 2° to 6° F higher in the cages than outside in the shade.

FIG. 1—Chinch bug cages on sorghum plants in the field.

In these cages fifth-instar nymphs collected in the field were confined on the varieties or hybrids to be tested. First-generation bugs were collected from spring barley and second-generation bugs from Dwarf Yellow milo. When the bugs reached the adult stage, they were paired, and five pairs placed in each cage and three cages on each plant at different heights. In most cases 5 to 10 plants of each variety or hybrid were used. Egg counts were made once each week.

Two plantings of sorghums were made, one on April 30 to be tested with first-generation bugs, and the other on June 27 to be tested with second-generation bugs. Eleven F_1 hybrids and their parents were grown.[4]

EXPERIMENTAL RESULTS

Table 1 shows the percentage of plants killed in the field and the average number of eggs laid per female by chinch bugs, both in the laboratory and under field conditions, on four typical sorghum varie-

[4]The seed of the hybrids and parental varieties was furnished by J. C. Stephens, of the Bureau of Plant Industry, located at Texas Agricultural Experiment Station Substation No. 12, Chillicothe, Tex.

ties. On seedling plants in the laboratory the fewest eggs were laid on feterita, whereas under field conditions more eggs were laid on this variety than on either Blackhull kafir or Atlas sorgo. When the number of eggs laid while the bugs were confined to plants growing in the field was used as a criterion for measuring resistance, the Dwarf Yellow milo was the most susceptible, followed in order by feterita, Blackhull kafir, and Atlas sorgo. These varieties were ranked in this same order when resistance was determined by percentage of plants killed in the field.

TABLE 1.—*Resistance of several varieties of sorghum to the chinch bug, as measured by the percentage of plants killed in the field and by the number of eggs laid per female in the laboratory and in field cages.*

Variety	C. I. No.*	Percentage of plants killed in the field†	Number of eggs laid in laboratory‡	Number of eggs laid in field cages§
Dwarf Yellow milo...	332	100	99.4	188.8
Feterita............	182	51	1.7	148.7
Blackhull kafir.......	71	23	21.2	104.6
Atlas sorgo..........	899	13	3.9	97.9

*Accession number of the Division of Cereal Crops and Diseases, Bureau of Plant Industry.
†Four-year average.
‡Average for three generations of bugs, 1936.
§Average for two generations of bugs, 1937.

Oviposition records of chinch bugs feeding on 11 F_1 sorghum hybrids and their parents are shown in Table 2. In most cases more eggs were laid by the second-generation bugs than by those of the first generation. This difference was not very great, however, and the relative resistance of the different varieties for the two generations was very similar. When one or both parents were resistant, the F_1 hybrids also were resistant. One possible exception to this was Texas Blackhull kafir × Day milo, which might be considered as intermediate. The results strongly indicate a dominance of resistance in these crosses. In several cases the hybrid was more resistant than either parent, indicating the presence of complementary cumulative factors for resistance. In crosses between two susceptible varieties the hybrids were susceptible, although an apparent exception to this was feterita × (feterita × milo), in which an average of only 80.8 eggs per female were laid on the feterita parent. This, however, probably was due to the very weak plants that were produced from the seed used.

When the egg data were analyzed statistically by the method of analysis of variance (2), it was found that on the whole the differences in the number of eggs laid on the several varieties and hybrids were highly significant.

The average length of life of chinch bug females (Table 2) feeding on the different varieties ranged from 25.0 days on Texas Blackhull kafir × Dwarf Yellow milo to 46.2 days on feterita. In general, the bugs lived longer when feeding on susceptible than on resistant varieties, but the differences were not very great, and the data are too limited to warrant making general conclusions. The analysis of variance, however, showed that differences in the length of life of females feeding on the several varieties and hybrids were highly

TABLE 2.—*Oviposition and longevity of chinch bug females on 11 F_1 sorghum hybrids and their parents.*

Hybrid or parent	Record No.*	Average number of eggs per female: First generation	Second generation	Mean	Average duration of life in days: First generation	Second generation	Mean
Sumac sorgo	S. P. I. 35038	72.1	89.3	80.7	40.0	40.7	40.3
Texas Blackhull kafir × Sumac sorgo		44.5	76.0	60.2	25.8	30.5	28.1
Texas Blackhull kafir	F. C. 8962	79.2	84.5	81.8	39.3	30.0	34.6
Atlas sorgo	C. I. 899	64.9	80.8	72.8	38.5	31.2	34.8
Atlas × Dwarf Yellow milo		67.3	—	—	29.8	—	—
Dwarf Yellow milo	C. I. 332	172.5	196.1	184.3	41.3	33.7	37.5
Feterita × milo	F. C. 8926	194.5	187.7	191.1	43.3	39.8	41.5
Texas Blackhull kafir × (feterita × milo)		67.3	—	—	27.1	—	—
Texas Blackhull kafir	F. C. 8962	79.2	84.5	81.8	39.3	30.0	34.6
Texas Blackhull kafir × Dwarf Yellow milo		73.8	85.5	79.6	28.1	21.9	25.0
Dwarf Yellow milo	C. I. 332	172.5	196.1	184.3	41.3	33.7	37.5
Feterita	C. I. 182	146.7	150.7	148.7	49.5	43.0	46.2
Texas Blackhull kafir × feterita		73.1	87.8	80.4	34.7	42.6	38.6
Texas Blackhull kafir	F. C. 8962	79.2	84.5	81.8	39.3	30.0	34.6
Dwarf Yellow milo	C. I. 332	172.5	196.1	184.3	41.3	33.7	37.5
Darso × Dwarf Yellow milo		70.7	92.7	81.7	26.8	25.6	26.2
Darso	F. C. 6606	91.9	95.7	93.8	36.1	32.0	34.0
Texas Blackhull kafir × darso		69.4	106.5	87.9	39.0	35.1	37.0
Texas Blackhull kafir	F. C. 8962	79.2	84.5	81.8	39.3	30.0	34.6
Texas Blackhull kafir × Day milo		100.4	113.1	106.7	37.1	45.5	41.3
Day milo	C. I. 480×332-187	106.6	167.2	136.9	39.7	47.1	43.4
Feterita × milo	F. C. 8926	194.5	187.7	191.1	43.3	39.8	41.5
(Feterita × milo) × Dwarf Yellow milo		138.6	—	—	39.1	—	—
Dwarf Yellow milo	C. I. 332	172.5	196.1	184.3	41.3	33.7	37.5
Dwarf White milo × Dwarf Yellow milo		194.8	169.9	182.3	45.1	40.4	42.7
Dwarf White milo	F. C. 8927	150.2	188.8	169.5	40.4	34.4	37.4
Feterita†	F. C. 811	80.8	—	—	35.5	—	—
Feterita × (feterita × milo)		202.8	205.5	204.1	50.0	39.3	44.6
Feterita × milo	F. C. 8926	194.5	187.7	191.1	43.3	39.8	41.5

*Accession numbers: S.P.I., Division of Plant Exploration and Introduction; F. C., Division of Forage Crops and Diseases; C. I., Division of Cereal Crops and Diseases, all of the Bureau of Plant Industry.

†This variety germinated very poorly, and the plants were weak throughout their life.

TABLE 3.—*Height, diameter of stalk, and tillering of 11 F_1 sorghum hybrids and their parents in relation to the number of eggs laid by chinch bugs.*

Hybrid or parent	Record No.	Heterosis	Average height of plant, inches	Average diameter of stalk at base, inches	Average number of stalks per plant	Maturity	Average number of eggs laid per female
Texas Blackhull kafir × Sumac sorgo	———	Medium	70.5	1.06	1.9	Late	60.2
Texas Blackhull kafir × (feterita × milo)	———	Medium	69.0	1.06	2.3	Late	67.3
Atlas sorgo × Dwarf Yellow milo	———	Much	90.7	1.28	4.5	Late	67.3
Atlas sorgo	C. I. 899	———	68.0	0.94	3.5	Late	72.8
Texas Blackhull kafir × Dwarf Yellow milo	———	Much	94.0	1.39	2.8	Late	79.6
Texas Blackhull kafir × feterita	———	Medium	72.0	1.06	2.8	Medium	80.4
Sumac	S. P. I. 35038	———	66.0	0.90	1.7	Late	80.7
Feterita*	F. C. 811	———	47.0	0.63	2.0	Late	80.8
Darso × Dwarf Yellow milo	———	Much	84.5	1.57	2.3	Late	81.7
Texas Blackhull kafir	F. C. 8962	———	51.5	1.18	1.1	Medium	81.8
Texas Blackhull kafir × darso	———	Medium	55.0	1.06	1.4	Medium	87.9
Darso	F. C. 6606	———	46.5	0.93	1.9	Medium	93.8
Texas Blackhull kafir × Day milo	———	None	43.0	0.96	1.6	Medium	106.7
Day milo	C. I. 480 × 332–187	———	25.0	0.84	2.0	Early	136.9
(Feterita × milo) × Dwarf Yellow milo	———	Much	88.0	1.25	4.3	Late	138.6
Feterita	C. I. 182	———	60.5	0.76	2.9	Early	148.7
Dwarf White milo	F. C. 8927	———	47.5	0.81	3.1	Medium	169.5
Dwarf White milo × Dwarf Yellow milo	———	None	47.0	0.97	3.2	Medium	182.3
Dwarf Yellow milo	C. I. 332	———	54.0	1.12	3.0	Medium	184.3
Feterita × milo	F. C. 8926	———	48.0	1.00	2.8	Medium	191.1
Feterita × (feterita × milo)	———	Medium	65.0	0.96	3.3	Early	204.1

*This variety germinated very poorly and produced very weak plants.

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significant. When the average length of life of the female was correlated with the average number of eggs laid, the correlation coefficient was 0.686.

Characteristics of the sorghum hybrids and their parents that indicate relative vigor, *viz.*, height of plant, diameter of stalk, and number of tillers, are shown in Table 3. The number of eggs laid by females caged on the different strains did not appear to be correlated with hybrid vigor. Atlas sorgo×Dwarf Yellow milo, darso×Dwarf Yellow milo, Texas Blackhull kafir×Dwarf Yellow milo, and (feterita ×milo)×Dwarf Yellow milo showed extreme hybrid vigor. The first three of these hybrids can be classed as resistant and the last one susceptible, when the number of eggs laid is the criterion of resistance. Five of the hybrids, Texas Blackhull kafir×Sumac sorgo, Texas Blackhull kafir×(feterita×milo), Texas Blackhull kafir×feterita, Texas Blackhull kafir×darso, and feterita×(feterita×milo), were only slightly taller than either of their parents. Of this group the first four can be classed as resistant and the last one as very susceptible. Texas Blackhull kafir×Day milo was intermediate in height between its two parents. This hybrid appeared to be intermediate in resistance. Dwarf White milo×Dwarf Yellow milo was slightly shorter than either of its parents.

It appears from the data in Table 3 that fewer eggs were laid on late-maturing strains than on strains maturing early or intermediate. This probably is a mere coincidence, partly because two of the resistant parental varieties, *viz.*, Atlas and Sumac, are inherently late, and partly because in certain hybrids complementary factors for growth and late maturity, as well as complementary genetic factors for chinch bug resistance, were brought together. Time of maturity among varieties has shown no relation to chinch bug injury (3). Data on maturity are shown in Table 3, because late maturity is a common manifestation of hybrid vigor.

The method used and the results obtained in these experiments should serve as useful guides in breeding for increased resistance to chinch bug injury by indicating which hybrid combinations appear to carry cumulative factors for resistance and thus offer the greatest promise. The Texas Blackhull kafir×Sumac sorgo hybrid appeared to be more resistant than Atlas sorgo, one of the most resistant varieties of sorghum among the many that have been tested. This hybrid is being grown and selected with the hope of isolating homozygous strains that are more resistant than any variety now available.

SUMMARY

The determination of the inheritance of chinch bug resistance in sorghums by measuring the injury to the plants has been impossible because of the frequent occurrence of hybrid vigor in the plants, which enables them to escape serious injury. Chinch bugs confined on the stems of field-grown plants of susceptible sorghum varieties by means of small celluloid cages laid more eggs than those similarly confined on resistant varieties. Egg counts thus obtained offer a method for determining the genetics of resistance to chinch bug injury and for

indicating in the F_1 generation which crosses offer the greatest promise in breeding for resistance. When this criterion was used to measure chinch bug resistance, the data from 11 sorghum hybrids in the F_1 generation and their parents indicate that in most of the crosses resistance was dominant to susceptibility. The extent of hybrid vigor as measured by height of plant, diameter of stalk, and number of tillers did not appear to be definitely associated with chinch bug resistance as measured by oviposition and longevity of the females. In general, chinch bug females lived longer on the susceptible varieties, but the difference was small, and the duration of life is a poorer criterion for measuring chinch bug resistance than is the number of eggs laid.

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SATURATION DEGREE OF SOIL AND NUTRIENT DELIVERY TO THE CROP[1]

WM. A. ALBRECHT AND N. C. SMITH[2]

WITH the better understanding of the physico-chemical aspects of the clay fraction of the soil, the mysteries of the migration by the nutrient ions from the soil into the plant are rapidly submitting to solution. In fact, we now know that the reverse movement is possible, so that in fertility-depleted soils the nutrients may be going back to the soil to reduce the cation stock in the plant originally contributed by the seed. The colloidal phenomenon of exchange of cations is helping us to understand soil fertility more clearly. With more research attention to the anions, even these may let their behavior come within the pale of understanding. If the colloidal system in the plant root is opposed to the colloidal clay system with the not wholly invulnerable root membrane interposed, we may look to equilibrium of forces within and without as a helpful explanation. Should we reason on this simple physico-chemical basis, then the questions naturally arise whether soil fertility applications should be an attempt to provide but that needed for most economic service to the plant, or that for modification of the soil. It becomes a question whether applied nutrients should be used to saturate highly limited soil areas in the immediate root zone or to give low degree of saturation of the soil throughout the plowed layer of the common 2 million pounds.

This viewpoint prompted an experimental study of the degree of saturation of the soil by calcium as cation and by phosphate as anion as a factor in plant growth and in the movement of these ions from the soil into the crop as nutrient harvest.

PLAN OF EXPERIMENT

An extensive series of 2-gallon pots of surface soil of the Putnam silt loam was arranged to include treatments of one-fourth of the soil with calcium in amounts equivalent to that needed to saturate it completely; and but one-half that quantity. These same amounts of the calcium were also distributed through the entire soil. Additions of phosphate representing 100 pounds and 200 pounds of 38% phosphate per 2 million pounds of soil were applied in similar manner.

Thus, in the case of calcium, there were jars in which the upper fourth of the soils was completely saturated; some in which the deficit in calcium in this layer was remedied by but one-half; some in which only a light application was given to the entire soil body; and another in which it was given a heavier application. These latter two treatments amounted to roughly 600 and 1,200 pounds per 2 million pounds for a soil that had an initial pH of 5.6 and was originally only about half saturated with calcium. This soil was also low in soluble phosphorus and responds readily to such application by better crop yield. It gives, however, the best responses to lime alone, and to phosphates used in conjunction with lime. For purpose of convenience these treatments will be spoken of in the case of the

[1]Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo. Journal Series No. 655. Received for publication January 6, 1940.

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limestone treatments as (a) partial saturation and (b) complete saturation; and in the case of phosphate treatments as (c) light dosage and heavy dosage in either case of treatment through the larger or the smaller soil volumes.

In mineral nature, this surface soil of the Putnam silt loam contains few, if any, "other than quartz" minerals which carry calcium. The subsoil is an impervious clay containing a high percentage of the beidellite clay colloid with an exchange capacity of more than 65 M.E. per 100 grams of clay. The surface soil used carried approximately 15% clay of which the exchange capacity combined with that of the organic matter gave it a total capacity of about 18 M.E. per 100 grams of surface soil.

Four crops were used in quintuplicate for each treatment. These included two grasses, bluegrass and redtop, and two legumes, sweet clover and Korean lespedeza. These selections were made in accordance with the generally accepted fertility demands by these crops, ranking those for bluegrass and sweet clover above those for redtop and Korean lespedeza.

The growths were harvested as forages at regular intervals to give five harvests of quintuplicate pots as carefully weighed amounts on constant moisture basis. Analyses were made for their contents of calcium and phosphorus to determine the fertility harvest for these nutrients applied in contrast to such from the untreated soil.

EXPERIMENTAL RESULTS

FORAGE HARVESTS

The single outstanding result throughout the experiment is the much larger yields of forage and fertility harvest that resulted when the treatments were applied to only the smaller portion of the soil to give it the higher degree of saturation by the ion of the treatment. The increases in forage yields as percentage over the untreated soil are assembled in Table 1. Comparison of the second column of figures with the first under each separate crop shows the much larger percentage increases where the treatment was put into the smaller soil volume.

TABLE 1.—*Increases (percentage) in forage harvests from limestone and phosphate distributed through large and small soil volumes.*

Soil treatment		Grasses				Legumes			
		Redtop		Bluegrass		Lespedeza		Sweet clover	
Kind	Magnitude	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.
Limestone	Partial saturation	15.5	15.5	−3.8	9.7	4.8	13.7	25.1	50.1
	Complete saturation	1.0	36.0	0.0	33.0	2.5	28.0	23.2	89.1
Phosphate	Light dose	8.8	4.3	9.0	34.4	20.0	23.0	22.8	51.0
	Heavy dose	14.3	12.3	15.7	18.0	21.4	22.4	27.2	70.8

In the case of limestone this increase held for the nonlegumes as well as for the legumes. In fact the figures for the former were generally larger than those for Korean lespedeza, though not as large as those for sweet clover. The yields show clearly that, as measured by forage increases, the higher degree of saturation by calcium in a limited soil area was more effective than a moderate or less degree of saturation in a larger soil area. This raises the question, and answers it forcefully, whether the economical use of lime is not one of feeding the plant calcium more than one of neutralizing the entire soil area of the root zone.

Phosphate, like the calcium carbonate, also showed more influence on the crop yield when the treatment was concentrated into a part of the soil, though this illustration was not as pronounced, in general, as that of the effects by the limestone. In the case of sweet clover, the effects by phosphates were almost equivalent to those by limestone in terms of percentage yield increase. For both the single soil treatments of calcium and phosphate additions in general, the crop yield increases were larger as the treatment was used to give a higher degree of soil saturation.

FERTILITY HARVEST OF CALCIUM

Analyses of the crops for calcium when lime was applied show that the crop content of this plant nutrient as totals per acre responded with larger differences in the increases than was the case for the forage yields. The higher degree of soil saturation by the application of the calcium into a limited soil area gave increases as much as 2½ times as large as where this same amount was distributed through more soil. This is demonstrated clearly in Table 2. Again, the nonlegumes demonstrated increases in calcium harvested from the soil which were

TABLE 2.—*Increases (percentages) in calcium and phosphorus harvests from limestone and phosphate distributed through large and small soil volumes.*

Soil treatment		Grasses				Legumes			
		Redtop		Bluegrass		Lespedeza		Sweet clover	
Kind	Magnitude	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.
		Calcium Harvest							
Limestone	Partial saturation	19.5	45.0	16.2	58.6	12.6	27.7	34.2	59.5
	Complete saturation	37.7	87.5	48.7	129.0	21.0	43.9	46.0	94.0
		Phosphorus Harvest							
Phosphate	Light dose	31.0	6.0	27.3	70.0	41.3	41.3	28.0	94.0
	Heavy dose	16.0	23.4	43.6	34.4	39.1	46.7	29.6	130.0

even greater than the increases taken by the legumes. Redtop was superior in this respect to Korean lespedeza, and bluegrass to sweet clover. It suggests that because these crops manage to produce vegetation on soils low in lime, we have perhaps not been giving sufficient attention to the capacity of the grasses to take lime for their possible improved feeding value.

FERTILITY HARVEST OF PHOSPHORUS

The total phosphorus harvested in the crops where the soils were given phosphates shows greater increases when the treatment was concentrated into the lesser amounts of soil for all but two of the eight cases as given in Table 2. Redtop and Korean lespedeza with the lower phosphate applications failed to give greater increases where the phosphate was applied in the surface soil only. In the other cases the differences were very significant and larger than any others in the case of sweet clover. In terms of forage, of calcium harvest, and of phosphorus harvest through the crop, this last crop showed the outstanding response to both calcium and lime applications into the limited soil area.

The crop responses rank these crops in the order as they are commonly arranged in fertility requirements. The bluegrass and the sweet clover showed greater response to the soil treatments than was true for the other two. They also removed larger amounts of calcium and phosphorus from the soil.

FERTILITY HARVEST OF NITROGEN

Since both nonlegumes and legumes were included, the significance of concentrating the calcium and phosphates into less soil as these influence nitrogen fixation by legumes and nitrogen removal from the soil can be measured. The data assembled into Table 3 are in agreement, in principle, with those previously given. The increases in

TABLE 3.—*Increases (percentages) in nitrogen harvests from limestone and phosphate distributed through large and small soil volumes.*

Soil treatment		Grasses				Legumes			
		Redtop		Bluegrass		Lespedeza		Sweet clover	
Kind	Magnitude	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.	Large soil vol.	Small soil vol.
Limestone	Partial saturation	−26.4	15.0	−18.5	14.3	20.0	30.6	39.8	67.3
	Complete saturation	−13.0	23.1	−4.5	40.8	13.0	52.4	35.4	113.7
Phosphate	Light dose	−12.8	−6.2	−15.5	25.0	47.3	54.0	25.9	65.1
	Heavy dose	−10.0	−10.0	−5.8	0	50.5	41.8	34.1	80.8

nitrogen harvested were much greater again where these soil treatments were used so as to provide them at higher degrees of soil saturation. Even for nonlegumes the higher concentration within the soil of the same application of limestone was much more effective in delivery of nitrogen from the supply in the soil to the crop. Small dosages or lower degree of saturation gave negative increases or amounts in the crop below that in crops on unlimed soil. This suggests that the introduction of limestone encouraged microbiological competition sufficient to utilize the effect by the calcium to the detriment of the crop competing for the supply of nutrients even other than calcium. Similar situations were provoked by the addition of the phosphatic fertilizers for the nonlegumes.

In the case of the legumes, the treatments all increased crop yields. The Korean lespedeza, however, was not correspondingly responsive to the higher applications of phosphate into the smaller soil volume. The sweet clover gives distinct evidence of the influence by both the calcium and the phosphate on the nitrogen increase by this crop, but especially of the effects when these treatments are concentrated into small soil volumes to give them higher degrees of nutrient ion saturation. Thus in this crop the higher nitrogen harvest, probably much through nitrogen fixation, agrees with the higher fertility delivery as calcium and phosphorus by the soil to the plant.

DISCUSSION AND SUMMARY

The data all emphasize the fact that more nutrients were delivered by the crops because of the higher degree of the soil saturation even of only a limited part of the soil. This area of soil was seemingly large enough to prohibit injury through excessive salt concentrations. These increased movements of the nutrients into the crops were roughly paralleled by increases in forage yields, though not directly so. Thus, there has resulted in most cases increased concentration of nutrients within the crops to give them higher forage feed value. Thus, the efficiency of the treated soils in terms of tonnage yield per unit of nutrient delivered is lower than the efficiency of the untreated soils, but it may be far more efficient in producing an animal feed of higher calcium, phosphorus, and protein concentrations. The increased use of nitrogen by the crop points to the significance of calcium and phosphorus in making this phase of plant metabolism operate effectively in case of the nonlegumes as well as for legumes.

Since calcium and phosphorus are the two most significant soil needs in the corn belt, as shown by past agronomic experience, by soil development, and by crops in their ecological array, we may well look forward to their wider use. For more effectiveness in practice, however, limestone and phosphate should be applied in more limited soil areas rather than distributed through the soil zone. Possibly not only the concentration within limited soil zones should deserve consideration, but also some efforts toward retardation of their rate of adsorption for reaction with the soil. Effectiveness of granular forms of such soil treatments may be premised on the greater efficiency of the nutrients when in areas of higher degrees of saturation. Efforts to

improve applications for such effectiveness should give results in terms of crop increases.

Since the very acid clay is active even to the point of removing calcium from the mineral lattice[3] and since a calcium clay is not so active in the removal of bases from plant roots,[4] perhaps the higher degree of calcium saturation in limited soil areas lessens the activity by the soil in adsorbing the anion phosphorus. If this is the case, then the applied phosphorus remains longer in the soil without reacting with it and may explain, in part, the greater efficiency of phosphates when used on limed soils[5] or those liberally stocked with calcium.

These results suggest most forcefully that in liming and fertilizing the soil, attention must go to the degree of saturation of the soil. The use of such soil treatments will be more effective when applied in limited soil areas to feed the plant than when applied through greater areas to modify the soil condition.

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[3]GRAHAM, ELLIS R. Primary minerals of the silt fractions as contributors to the exchangeable base level of acid soils. Soil Science (In press).

[4]JENNY, HANS, and OVERSTREET, R. Cation interchange between plant roots and soil colloids. Soil Sci., 47:257–272. 1939.

[5]ALBRECHT, WM. A. and KLEMME, A. W. Limestone mobilizes phosphates into Korean lespedeza. Jour. Amer. Soc. Agron., 31:284–286. 1939.

NOTES

SPACING OF CORN USED AS GREEN MANURE

IN PLANNING an experiment in which corn was to be grown as a green manure crop the question arose as to how thick it should be seeded and what would be the effect of close spacing of the plants on their nitrogen content. Various reports in the literature on rate of planting show that the tonnage of stover increases with close spacing beyond the point where the yields of grain decline. No data were found, however, to show what rate would give the largest tonnage of dry matter irrespective of the grain yield. Preliminary tests were made in 1932 at the Experiment Station Farm at Wooster, one on Canfield silt loam, the other on nearby Chippewa loam. Inquiries regarding the results have indicated enough interest to justify this brief report.

Blue Ridge, a variety with too long a season to mature grain in northern Ohio, was planted by hand in duplicated plots 18 feet square at the spacings indicated in Table 1. Ten representative plants from each plot were cut close to the soil in late September, weighed at once, and taken to the laboratory where they were thoroughly chopped and minced, ears included, and small aliquots taken for the determinations of dry matter and nitrogen. The data given in Table 1 are averages of the duplicate plots.

TABLE 1.—*Dry matter and nitrogen content of Blue Ridge corn plants at close spacing.*

Spacing of plants, inches	Plants per acre (calculated)	Yield of dry matter		Nitrogen content	
		Per plant, grams	Per acre, lbs.	Of dry matter, %	Per acre, lbs.
On Canfield Silt Loam, Planted May 24, Sampled Sept. 25, 1932					
32×12	16,335	172.2	6,203	0.99	61.4
24×12	21,780	128.9	6,190	0.98	60.7
16×12	32,670	123.6	8,900	0.77	68.5
12×12	43,560	115.0	11,044	0.59	65.2
8×12	65,340	80.9	11,655	0.58	67.6
On Chippewa Loam, Planted May 24, Sampled Sept. 20, 1932					
32×12	16,335	347.2	12,505	0.760	94.9
24×12	21,780	261.5	12,557	0.765	96.1
16×12	32,670	199.7	14,383	0.700	100.7
12×12	43,560	145.5	13,974	0.625	87.3
8×12	65,340	106.3	15,310	0.585	89.6

The data calculated to an acre basis show that the closer spacing resulted in a larger production of total dry matter, a decline in the percentage of nitrogen in the dry matter, and a fairly constant nitrogen content per acre. The uniformity of the nitrogen content per acre suggests that nitrogen was a limiting factor, and that the plants spaced 32×12 inches were able to use the available nitrogen as effectively as the closer spaced plants. In comparing the data from

the two soils, the more fertile Chippewa soil produced distinctly larger amounts of dry matter, but the percentage of nitrogen was no higher than on the Canfield soil.

Corn grown for ensilage in Ohio, in rows 42 inches apart, harvested in September, usually analyzes about 1% of nitrogen on a dry matter basis. At the closer spacing of this test, or when seeded with a grain drill in subsequent tests, the corn, sampled in September, has been characterized by a nitrogen content of only 0.6% of the dry matter.

A crop with such a low nitrogen content ordinarily would not be considered suitable for green manure purposes. It is being used experimentally on heavy soils with the aim of incorporating sufficient bulk of coarse organic matter to improve the drainage and aeration of the plowed horizon. With potatoes as the test crop, any procedure which improves the aeration has proved beneficial.[1] The anticipated nitrogen deficiency arising from the presence of the corn residue in the soil has been corrected by a moderate increase in the proportion of nitrogen in the potato fertilizer.—JOHN BUSHNELL, *Ohio Agricultural Experiment Station, Wooster, Ohio.*

AN INEXPENSIVE PHOTO-ELECTRIC COLORIMETER FOR PHOSPHORUS DETERMINATION

TO increase the sensitivity of the colorimetric quick test for available phosphorus in soil, the apparatus illustrated here was built. A standard beam of light is projected through a fixed quantity of the blue solution in a standard flat-sided, glass jar and on to the lens of a photographer's photo-electric exposure meter. By using for comparison solutions of known phosphorus content the dial of the meter can

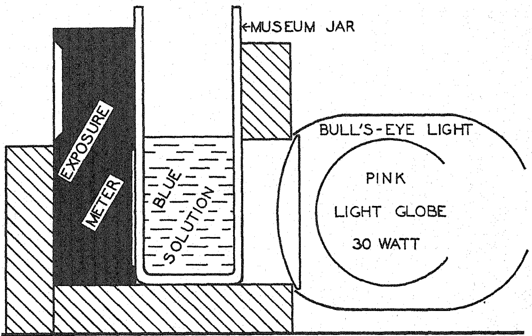

FIG. 1.—Inexpensive photo-electric colorimeter for phosphorus.

[1]BUSHNELL, JOHN. Sensitivity of the potato plant to soil aeration. Jour. Amer Soc. Agron., 27:251–253. 1935.

be calibrated to read directly in parts of available phosphorus per million parts of soil. This apparatus seems to be both more sensitive and more accurate than matching colors by eye.

The construction of the apparatus is easily seen from the diagram (Fig. 1). For routine analysis an ordinary 30 watt pink (for contrasting wave lengths) electric light globe in a cheap bull's-eye spot light seems to be a satisfactory source of light. A check with distilled water will show if there is any variation in intensity. A rectangular glass museum jar of 150 ml. capacity makes a satisfactory container for the blue solution. A box to hold the parts in position may be made of wood with an opening at the front for the light, at the rear for reading the dial of the meter, and at the top for inserting the meter and jar.

Experience shows that different exposure meters of the same make and model may differ very widely in their reading, but each meter seems to be quite constant in itself, and the calibration of each meter may be used with confidence for some time.—D. W. PITTMAN and R. PARRY, *Agricultural Experiment Station, Logan, Utah.*

SMALL GRAIN BUNDLE TIER

IN a previous article[1] a machine for tying rod-row bundles of the small grains was described. During the intervening years it has become apparent that a larger and more flexible piece of equipment would be desirable—a machine that would use a heavier twine, tie bundles tighter, tie several bundles together, and be power driven.

During the past harvest season the assembly described herein was used and proved highly successful. It tied single bundles tightly enough so that slippage was negligible and from two to five bundles were tied together without difficulty. The speed and operation of the machine was only limited by the operator's ability to supply it with bundles. Common binder twine was used and twine cost was reduced to a minimum because the machine uses the minimum length of twine when making a band.

The machine (Fig. 1) was made by mounting the binding mechanism of the smallest new Light Running John Deere binder together with a small gasoline engine on an old Ford chassis. The jackshaft mounted between the engine and the binder was necessary to reduce the engine speed and change from belt to chain drive. No clutch other than that built into the binding mechanism is included on our machine, but it would be convenient to have one in the jack-shaft assembly. In both figures the needle is shown protruding above the table, but in the neutral position it is completely below it.

A close-up of the working table and tying mechanism is shown in Fig. 2. The original needle guide and straw guard were removed and replaced by the iron straps and sheet metal shown in the picture. Also, the knife holder of the knotter assembly was removed and shortened so as to allow the bundle to come closer to the knotter bills and be tied more tightly. The original equipment gave a very loose tie on small bundles.

[1]Jour. Amer. Soc. Agron., 28:395–403. 1936.

An important item of the assembly which is not clearly seen in either picture is a long rubber band (a light spring would function as well) which serves as a tension on the twine. The band is attached

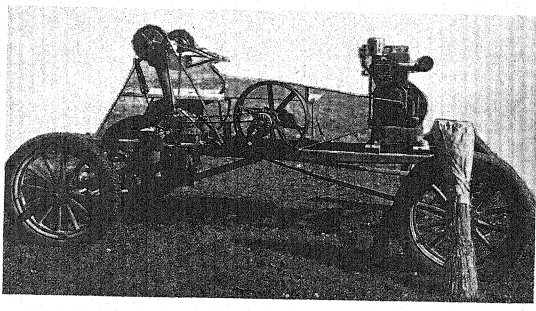

FIG. 1—The binding machine.

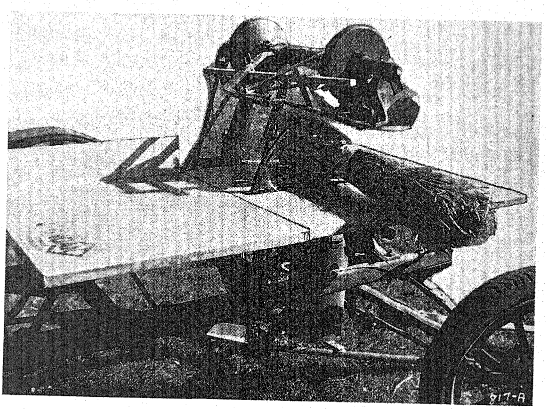

FIG. 2.—Working table and tying mechanism.

to a metal eye which is slipped over the twine between the gear tension of the original equipment and the point where the twine enters the needle. This is necessary to make the needle follow up the twine and take up slack and is the secret to tying small bundles tightly.

The tying mechanism is actuated by a slight tap of the hand on the trip-lever which in turn engages the clutch of the drive assembly. A small rubber band prevents the trip chain from becoming tangled. If the trip lever fails to return to the neutral position, the tying mechanism continues to run.

The bundles, ready for tying, are passed to the operator from the left. He presses the bundle against the twine until it is directly under the knotter and then presses the trip lever. The needle comes up from the left carrying the twine on around the bundle and into the knotter. As the tie is made, the operator gives the bundle a quick downward jerk which removes the tie from the knotter bills. The tied bundle comes free below the twine, the same as in any binder. One operator can tie bundles with two bands as fast as two helpers can roll the sacks properly for tying and hand the bundles to him.

In the ground driven binder, the packer shaft, which is the drive member for the binding head, makes 171 r.p.m. at 2½ miles per hour and the needle shaft makes 57 r.p.m. The machine we are using runs the needle shaft at 15 r.p.m., a very satisfactory speed.

Any good mechanic should be able to make a satisfactory assembly similar to the one herein described.—JAMES W. THAYER, JR., and HUBERT M. BROWN, *Michigan State College, East Lansing, Mich.*

EFFECTS OF INBREEDING LITTLE BLUESTEM[1]

IN a recent paper,[2] the writer indicated that in little bluestem (*Andropogon scoparius*) there appeared to be considerably less reduction in vigor following inbreeding than occurred in big bluestem (*A. furcatus*). The inbred plants reported at that time showed no significant decrease in size as compared to the open-pollinated lines. This test included approximately 50 plants in their first inbred generation. Later tests with other lines of little bluestem have shown that, while the vigor of certain lines is only slightly if at all affected by inbreeding, there are lines which give rather marked losses of

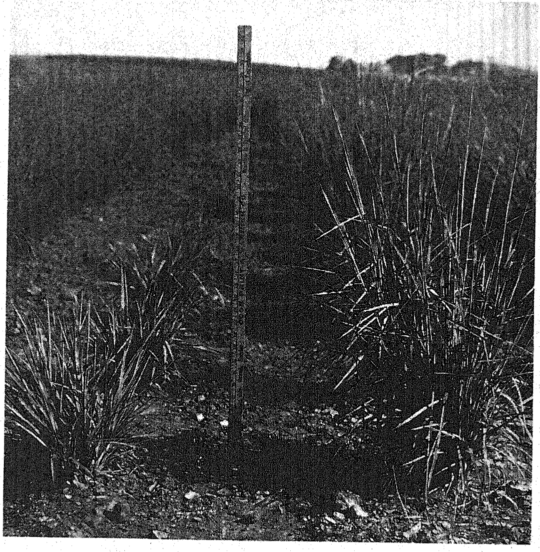

FIG. 1.—Little bluestem (*Andropogon scoparius*). A line showing marked reduction of vigor following inbreeding. The row on the left is the selfed progeny and the one on the right the open-pollinated progeny of an S_1 plant.

[1]Contribution No. 300, Department of Agronomy, Kansas Agricultural Experiment Station, Manhattan, Kan.

[2]ANDERSON, KLING L., and ALDOUS, A. E. Improvement of *Andropogon scoparius* Michx. by breeding and selection. Jour. Amer. Soc. Agron., 39:862–869. 1938.

vigor even in the first inbred generation. Variations appeared in the response of the various plant lines studied, however, and observational data indicated that little bluestem generally shows smaller reduction in vigor from inbreeding than does big bluestem.

In Fig. 1 are shown two rows of progeny of a plant in its first inbred generation, the left row from selfed and the right from open-pollinated seed of this plant. The inbred row, now in the S_2 generation, shows considerable reduction in vigor as compared to the inbred row shown in Fig. 2.

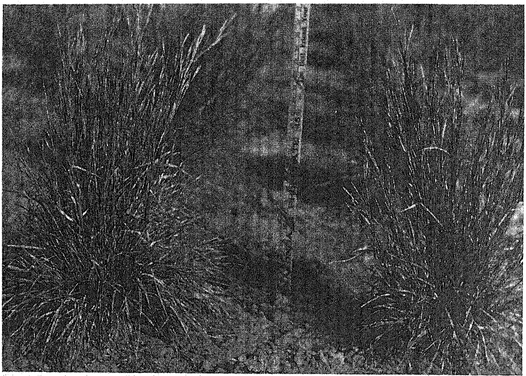

FIG. 2.—Little bluestem (*Andropogon scoparius*). A line in which inbreeding has no marked effect in reducing vigor. Both rows shown are the progeny of the same S_2 plant, the left hand row having been grown from open-pollinated seed and the right hand row from seed that was selfed.

The illustration in Fig. 2 is a photograph of two progeny rows from a plant in its second inbred generation, the row on the right having been grown from selfed and the row on the left from open-pollinated seed of this plant. This line, even in the S_3 generation shows a great deal smaller reduction in vigor than does the line shown in Fig. 1 in its S_2. The inbred is somewhat less leafy than the open-pollinated row from the same mother plant, but it has grown to the same height and has seeded normally.—KLING L. ANDERSON, *Kansas Agricultural Experiment Station, Manhattan, Kan.*

BOOK REVIEW

PLANT PHYSIOLOGY

By Bernard S. Meyer and Donald B. Anderson, New York: D. Van Nostrand Co. X+696 pages, illus. 1939. $4.50.

TO the growing list of excellent publications upon plant physiology must be added this one. It has been developed from the courses in plant physiology taught at the Ohio State University and the University of North Carolina by the authors. The attempt to "bring into bold relief the fundamental principles of plant physiology rather than to present only an encyclopedic compilation of undigested and sometimes contradictory facts" seems to have been measurably successful. Further, material from the supporting basic sciences has been injected in sufficient amount to make the book a complete unit in itself. The discussions of material from physics and chemistry are well presented, and the introduction of drawings and discussion on structure of organs, tissues, and cells is particularly welcome and helpful. The material is presented in 37 chapters, in turn well organized and subdivided into paragraphs with bold face headings. At the end of various chapters are lists of discussion questions, suggestions for collateral reading, and a selected bibliography. A subject and an author index complete the book. It is well printed with good-sized type and adequate spacing between lines to make for easy reading. (H.B.T.)

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RESEARCH MONOGRAPHS

President Alway has appointed a special committee of the Society to deal with the matter of research monographs as discussed at the recent meeting of the Association of Land Grant Colleges and Universities. Doctor Richard Bradfield has been named Chairman of the Committee, with M. A. McCall and J. D. Luckett as the other members.

The chief function of this special committee is to represent the Society in dealing with a committee representing the Association of Land Grant Colleges and Universities. At this time Doctor Bradfield and his committee would welcome suggestions from members of the American Society of Agronomy as to fields in which there is the greatest need for the proposed reviews, outstanding authorities who might be asked to prepare the monographs, and practicable means of publication.

In order to make possible a better understanding of the whole matter there is reproduced herewith the report of the committee of the Association of Land Grant Colleges and Universities as presented to the Association at its meeting in Washington, D. C., on November 14, 1939.

REPORT OF THE COMMITTEE ON RESEARCH MONOGRAPHS

At the 1938 meeting of the Association of Land Grant Colleges and Universities, the Joint Committee on Projects and Correlation of Research stressed the need of "monographs which will assemble, organize, condense, and evaluate available information on the more important subjects of agricultural research" so that new researches may be planned on the basis of a comprehensive knowledge of previous work. The committee recommended that the Office of Experiment Stations in the U. S. Dept. of Agriculture be requested to establish such a service; and that a committee of five be appointed "to determine the timely problems on which monographs should be prepared, and to advise with the Office of Experiment Stations in making plans for preparing and publishing the same." It was suggested that two members of this committee be appointed from the U. S. Dept. of Agriculture, two from the state experiment stations, and one from the National Research Council. These recommendations were approved by the Executive Body and the Executive Committee of the Association.

The committee has made a canvass of the U. S. Dept. of Agriculture and the state experiment stations as to subjects that are most in need of monographic treatment. The replies reveal widespread interest in the proposal, and the urgent need of the early preparation of certain monographs, as an aid in planning new research. Several hundred subjects have been suggested. Among those which appear to be of greatest interest are the following:

Effects of temperature and light on the growth and reproduction of plants.

Value of "trace elements" in animal and plant nutrition.

Role of minerals and of vitamins in animal nutrition.

Ensiling grasses and legumes.

Nutritive value of pasture grasses as influenced by soils, climate, and fertilizer treatments.

Nature of disease resistance in plants and animals.

Physiology and biochemistry of fungi.

Relation of soil organic matter to soil erosion.

Nature of soil colloids.

It is the opinion of the committee that the monographs should be on subjects that require fundamental research and that are of widespread interest. Before any monograph is undertaken the counsel and cooperation of interested agencies should be sought. To this end the committee proposes to supplement the data already gathered by requesting each of the national scientific societies which has a definite relation to agriculture to express its judgment on three points—subjects in its field that are in greatest need of such review, outstanding authorities who might be invited to prepare the monographs, and practicable means of publication.

The committee is of the opinion that the type of monograph which will be most serviceable is one which will review and appraise recent developments, having in mind primarily the needs of modern research, rather than one which is mainly historical.

The Committee on Projects and Correlation of Research suggested that the necessary funds might be provided by Congressional appropriation or by contributions from interested agencies. It is the judgment of this committee that it would not be practicable at this time to seek Congressional appropriations, but that the monographs be made possible through the cooperation of interested agencies such as the U. S. Dept. of Agriculture, the state agricultural experiment stations, scientific journals, commercial publishing houses, and by the sale of the monographs.

The committee recommends further that the monographs do not appear as a separate series, but in any existing channel of publication which may be most expedient, in each case, such as books that are printed and sold by publishing houses, publications of the U. S. Dept. of Agriculture and the state agricultural experiment stations, and scientific journals. The function of this committee, therefore, would be to cooperate with the Office of Experiment Stations in promoting and authorizing the monographs—not to publish them.

E. J. Kraus, National Research Council
C. B. Hutchison, California
O. E. Reed, U.S.D.A.
P. V. Cardon, U.S.D.A.
S. W. Fletcher, Pennsylvania.

SUMMER MEETING OF NORTHEASTERN SECTION

ANNOUNCEMENT has been made by Ralph W. Donaldson, secretary-treasurer of the Northeastern Section of the Society, that the 1940 summer meeting of the Section will be held at Pennsylvania State College July 11 and 12. During the meeting there will be an opportunity to visit the Pasture Research Laboratory located at State College. It is also stated that the ladies are included in the invitation.

NEWS ITEMS

Jacob Elry Metzger, Director of the Maryland Agricultural Experiment Station and head of the Department of Agronomy of the University of Maryland, died December 25, 1939, at Lake Worth,

Florida, where he had gone for a vacation and rest. Director Metzger was long a member of the American Society of Agronomy.

THE BAYER-SEMESAN COMPANY announces the following educational one-reel, sound-on-film motion pictures: "Black Scourge", "Feeding the Multitude", "Grain Thieves", "Seeds of Prosperity", "Peruvian Gold", "Tall Corn", "King Cotton", and a film of last year's national corn husking contest. For further information about the free use of these films, which are available both in standard 35 mm and 16 mm size, may be obtained by addressing Mr. J. Hunter Gooding, Jr., Bayer-Semesan Company, Wilmington, Delaware.

KARL MANKE, who for the past thre eyears has been in charge of the sweet clover breeding program at the Nebraska Agricultural Experiment Station under the direction of E. A. Hollowell, has accepted a position at the Texas Agricultural Experiment Station where he will continue the same line of research.

REPRESENTATIVES of the American Society of Agronomy and of the Soil Science Society of America have been designated for each of the states and the District of Columbia for the purpose of securing new members for the two societies and to act as correspondents for this JOURNAL. The list will be published in an early number of the JOURNAL.

ERRATUM

ATTENTION is called to the fact that the Rex barley described in the report on barley registration appearing in the January 1940 number of the JOURNAL (page 84) is a *two-rowed* barley; not six-rowed as stated in the published description.

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JOURNAL
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VOL. 32 MARCH, 1940 NO. 3

EFFECT OF "CLIPPING" OR RUBBING THE OAT GRAIN ON THE WEIGHT AND VIABILITY OF THE SEED[1]

G. H. CUTLER[2]

THE practice of clipping oat grains by mechanical means has been employed for many years. Its chief purpose is to increase the test weight, though it also helps to improve the appearance of the sample. Seedsmen and exhibitors at grain shows find that rubbing or clipping works very beneficial changes on oats. Even mediocre looking oats can be greatly improved in both test weight and general appearance by this so-called "face-lifting" process.

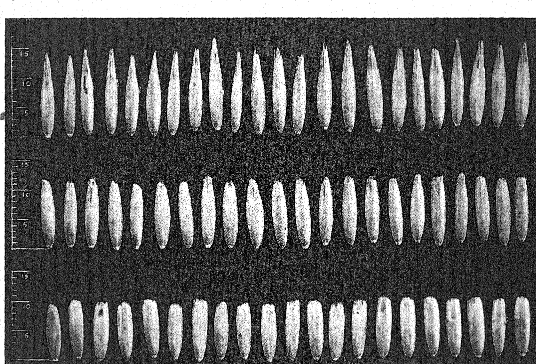

FIG. 1.—Representative grains of Cartier variety, showing treatment. Top row, no treatment (original); middle row, lightly rubbed; bottom row, heavily rubbed. 1.7 times natural size.

[1]Contribution from Dept. of Agronomy, Purdue University Agricultural Experiment Station, Lafayette, Ind. Also presented at the annual meeting of the Society held in New Orleans, La., November 22, 1939. Received for publication November 18, 1939.

[2]Assistant Chief and Professor of Agronomy.

Clipping, as is well known, consists in removing the tips or tails and awns from the hulls, as well as polishing and cleaning the grain so that all extraneous materials are removed. Some varieties of oats have more hull extending beyond the end of the meat or caryopsis than others. This, together with awns and other materials that may be attached to the exterior of the hull when removed, permits the oat grains to lie more closely together in a more compact and solid mass.

From the standpoint of the seed producer, the exhibitor, and even the feeder, clipping seems desirable. Whether it is fraught with detrimental effects to the seed, however, may be open to question. The purpose of this study was to ascertain the effect, if any, of clipping oats upon the viability or germinability of the seed.

It is generally agreed among agronomists that dehulled oats, when used as seed, are inferior to oats with hulls. Anderson[3] states that shelled (dehulled) oats were considerably inferior to unshelled oats, not only as regards viability and germinative energy but also in yield. He found that yield was reduced 20 to 25% in the case of the shelled oats. Bayles and Coffman[4] observed that dehulling oats reduced the germination 5.8% (field tests) and that as high as 6.3% of the plants failed to reach maturity.

It might be assumed, therefore, with some degree of logic that clipping the oat hull so closely as to expose the caryopsis might result in expediting the rate at which its viability is lost. Published data based on experimental tests are very meager on this point.

TABLE 1.—*The effect of rubbing oat grains of six varieties* of oats on the test weight, 1935 harvest crop.*

Varieties	Test weight				
	No treatment (original), lbs.	Lightly rubbed, lbs.	Heavily rubbed, lbs.	Total increase in weight	
				Lbs.	%
Alaska	33.3	39.6	43.4	10.1	30.3
Cartier	30.0	36.4	40.5	10.5	35.0
Minota	22.5	28.4	32.8	10.3	45.7
Columbia	32.8	37.7	42.9	10.1	30.7
Markton × Idamine (C. I. No. 2570)	27.2	33.5	37.4	10.2	37.5
Gopher A	25.1	31.9	35.2	10.1	40.2
Gopher B	23.7	30.7	33.9	10.2	43.0
Average	27.8	34.0	38.0	10.2	37.4

*Seven samples.

[3]ANDERSON, J. A. On the viability of shelled oats. Landannen, 13, No. 42: 676–678. 1902.

[4]BAYLES, B. B., and COFFMAN, F. A. Effects of dehulling seed and date of seeding on germination and smut infection in oats. Jour. Amer. Soc. Agron., 21: 41–51. 1929.

TABLE 2.—*The effect of rubbing oat grains of six varieties* of oats on the test weight, 1936 harvest crop.*

Varieties	Test weight: No treatment (original), lbs.	Lightly rubbed, lbs.	Heavily rubbed, lbs.	Total increase in weight: Lbs.	%
Alaska	38.2	42.2	45.0	6.8	17.8
Cartier	37.5	41.0	43.6	6.1	16.2
Minota	26.1	30.3	34.4	8.3	31.8
Columbia	36.5	40.6	44.3	7.8	21.3
Markton × Idamine (C. I. No. 2570)	32.9	37.7	40.8	7.9	24.1
Gopher A	35.1	37.9	41.8	6.7	19.1
Gopher B	32.3	36.4	39.7	7.4	22.9
Average	34.0	38.0	41.3	7.3	21.8

*Seven samples.

TABLE 3.—*The effect of rubbing oat grains of six varieties* of oats on the test weight, 1937 harvest crop.*

Varieties	Test weight: No treatment (original), lbs.	Lightly rubbed, lbs.	Heavily rubbed, lbs.	Total increase in weight: Lbs.	%
Alaska	34.1	40.5	42.4	8.3	24.4
Cartier	33.3	37.6	40.2	6.9	20.7
Minota	26.4	33.1	36.4	10.0	37.7
Columbia	31.2	37.9	41.4	10.2	32.6
Markton × Idamine (C. I. No. 2570)	28.5	35.6	39.5	11.0	38.5
Gopher A	30.8	36.0	38.6	7.8	25.3
Gopher B	31.4	36.4	39.1	7.7	24.5
Average	30.8	36.9	39.6	8.8	29.1

*Seven samples.

TABLE 4.—*Averages of six varieties* for 3 years 1935, 1936, and 1937.*

Years	Test weight: No treatment (original), lbs.	Lightly rubbed, lbs.	Heavily rubbed, lbs.	Total increase in weight: Lbs.	%
1935	27.8	34.0	38.0	10.2	37.4
1936	34.0	38.0	41.3	7.3	21.8
1937	30.8	36.7	39.6	8.8	29.1
Average	30.9	36.3	39.7	8.8	29.4

*Seven samples.

MATERIALS AND METHODS

The varieties studied in these tests include Alaska, Markton×Idamine (C. I. No. 2570), Cartier, Minota, Columbia, and Gopher. The last four are grown very extensively in Indiana. Two samples of Gopher were used. Gopher A was in good condition when clipped and stored, while Gopher B was musty when clipped and stored.

The technic of clipping consisted in rubbing or kneading about 3 pounds of seed at a time in a muslin sack that was about three parts filled. The sack of grain was grasped with both hands and vigorously kneaded and pressed against the surface of a heavy table. After treating the sample in this manner for a short time, it was passed through a strong current of air to remove the light chaffy materials. It was then divided with the Boerner sampler into two parts, one of which was retained and designated "lightly rubbed", while the other was again vigorously rubbed to improve further its appearance and test weight. The second rubbing treatment was sufficiently vigorous and effective to break away the hull at the end distal to the embryo and to expose the end of the meat or caryopsis. Even in some instances, the hull was split and the entire length of the caryopsis was exposed. This sample was again passed through a strong current of air to remove chaffy materials and designated "heavily rubbed" (Fig. 1).

TABLE 5.—*Germination tests of untreated (original), lightly rubbed, and heavily rubbed seed of six varieties* of oats grown in 1935 and stored 4, 16, and 40 months, respectively.*

Variety	Treatment	Percentage germination			
		Dec., 1935	Apr., 1936	Apr., 1937	Apr., 1939
Alaska	No treatment (original)	95.0	93.5	93.0	95.0
	Lightly rubbed	96.0	92.5	93.5	97.0
	Heavily rubbed	95.5	94.0	94.5	97.0
Cartier	No treatment (original)	93.5	92.5	93.0	95.5
	Lightly rubbed	94.5	94.0	91.5	95.0
	Heavily rubbed	93.0	93.0	92.0	96.5
Minota	No treatment (original)	93.0	93.5	93.0	94.0
	Lightly rubbed	95.0	92.5	95.0	94.5
	Heavily rubbed	93.0	92.0	95.0	94.5
Columbia	No treatment (original)	97.5	94.5	94.5	95.5
	Lightly rubbed	96.5	93.0	95.0	96.0
	Heavily rubbed	94.0	95.5	96.5	95.5
Markton × Idamine (C. I. No. 2570)	No treatment (original)	96.5	93.0	92.0	93.5
	Lightly rubbed	96.5	92.0	94.0	94.5
	Heavily rubbed	94.5	90.0	93.0	94.0
Gopher A	No treatment (original)	93.0	93.5	87.0	84.0
	Lightly rubbed	94.5	93.0	83.5	85.0
	Heavily rubbed	95.0	90.0	88.5	85.0
Gopher B†	No treatment (original)	89.0	89.0	75.5	70.0
	Lightly rubbed	91.0	85.5	78.5	70.5
	Heavily rubbed	86.5	84.5	78.0	72.5

*Seven samples.
†Sample slightly musty when rubbed and stored.

Before being placed in storage, tests for test weight were completed using the standard equipment for this purpose. The samples were then stored in a heated room in a galvanized container which was equipped with a close-fitting lid.

The germination tests were made in a Minnesota germinator in accordance with the official method recommended by the U. S. Dept. of Agriculture. A limited number of germination tests were also made in soil in the greenhouse.

EXPERIMENTAL RESULTS

EFFECT OF RUBBING THE OAT GRAIN ON THE TEST WEIGHT

The effect of rubbing oat grains on the test weight is shown in Tables 1, 2, 3, and 4 for the seed from crops harvested in 1935, 1936, and 1937, respectively.

The above data reveal that rubbing oat seed vigorously, followed by fanning, greatly increases the test weight. This was the case with all varieties and in all three seasons during which these tests were made. It is of interest to note that the lighter weighing oats were benefited relatively more than the heavier weighing samples. The Minota variety represents the light weighing variety while the Cartier and Alaska are among the heavy weighing varieties. The

TABLE 6.—*Germination tests of untreated (original), lightly rubbed, and heavily rubbed seed of six varieties* of oats grown in 1936 and stored 4 and 28 months, respectively.*

Variety	Treatment	Percentage germination		
		Dec., 1936	Apr., 1937	Apr., 1939
Alaska	No treatment (original)	96.5	96.5	94.5
	Lightly rubbed	97.0	97.5	97.0
	Heavily rubbed	97.5	96.0	97.5
Cartier	No treatment (original)	96.0	94.0	97.0
	Lightly rubbed	97.0	96.5	95.0
	Heavily rubbed	96.0	96.5	96.0
Minota	No treatment (original)	92.5	92.5	93.5
	Lightly rubbed	92.5	93.0	94.5
	Heavily rubbed	94.5	95.5	96.0
Columbia	No treatment (original)	97.5	97.5	97.0
	Lightly rubbed	96.5	95.5	97.0
	Heavily rubbed	97.0	97.0	97.0
Markton × Idamine (C. I. No. 2570)	No treatment (original)	93.0	96.5	93.5
	Lightly rubbed	93.5	95.5	93.5
	Heavily rubbed	93.0	95.5	95.5
Gopher A	No treatment (original)	95.5	93.5	96.5
	Lightly rubbed	95.0	95.0	95.5
	Heavily rubbed	96.0	94.0	95.0
Gopher B	No treatment (original)	95.0	93.5	93.0
	Lightly rubbed	96.0	93.6	96.0
	Heavily rubbed	96.5	93.5	95.5

*Seven samples.

average increase in test weight for the 3 years was nearly 9 pounds per bushel. Exhibitors have long taken advantage of this practice.

EFFECT OF RUBBING OAT GRAIN ON VIABILITY OF THE SEED

The effect of rubbing oat grains on the viability of the seed is shown in Tables 5, 6, and 7. The tests were conducted in the Minnesota germinator and included six varieties that were grown for three years, *viz.*, 1935, 1936, and 1937.

TABLE 7.—*Germination tests of untreated (original), lightly rubbed, and heavily rubbed seed of six varieties* of oats grown in 1937 and stored 12 months and 16 months, respectively.*

Variety	Treatment	Percentage germination		
		Dec., 1937	Dec., 1938	Apr., 1939
Alaska	No treatment (original)	99.0	97.5	97.5
	Lightly rubbed	96.0	97.5	98.0
	Heavily rubbed	99.0	98.0	99.0
Cartier	No treatment (original)	99.0	97.5	97.0
	Lightly rubbed	99.0	98.5	99.0
	Heavily rubbed	99.0	98.0	98.0
Minota	No treatment (original)	98.0	98.0	98.5
	Lightly rubbed	100.0	98.0	98.5
	Heavily rubbed	100.0	97.5	98.5
Columbia	No treatment (original)	100.0	97.5	98.5
	Lightly rubbed	98.0	98.5	98.5
	Heavily rubbed	97.0	98.0	99.0
Markton × Idamine (C. I. No. 2570)	No treatment (original)	99.0	97.0	97.5
	Lightly rubbed	100.0	97.0	98.5
	Heavily rubbed	98.0	97.5	98.5
Gopher A	No treatment (original)	96.0	98.5	98.5
	Lightly rubbed	98.0	99.0	98.5
	Heavily rubbed	97.0	99.5	99.5
Gopher B	No treatment (original)	99.0	98.0	97.0
	Lightly rubbed	97.0	98.5	98.5
	Heavily rubbed	98.0	98.5	98.0

*Seven samples.

The data in Tables 5, 6, and 7 show that the loss in viability of the oat seed is no greater when lightly or heavily rubbed than when untreated (Fig. 2). Even the Gopher B sample harvested in 1935 that was musty when rubbed and stored, though lower in viability throughout the period of test, retained its viability equally as well as when untreated. Furthermore, the length of the storage period seemed to have little, if any, differential effect upon the viability loss of the rubbed or clipped oats. It would seem therefore that considering all the conditions surrounding these experiments, the number of varieties and harvested crops studied, the varying duration of the storage period following clipping, there is small liklihood of increasing the

rate of deterioration in viability of the oat embryo by removing the tip or "tail" of the oat hull. The embryo of the caryopsis, the really vital and essential part concerned, is situated on the opposite end of the grain, is fully protected, and is therefore apparently not affected by this treatment. In the light of these data, one might well raise the question, Is a judge of oats justified in discriminating against clipped oats whose tips or "tails" have been removed in a show sample? If the viability and seed value is not jeopardized by "clipping" as is emphasized by the above data, it might seem that the question may well be raised by the exhibitor.

The effect of rubbing oat grains on the viability of the seed is shown in Table 8. The tests were conducted in soil in the greenhouse.

TABLE 8.—*Germination tests in soil in the greenhouse of untreated (original), lightly rubbed, and heavily rubbed seed of six* varieties of oats grown in 1935 and stored 2 years and tested in January 1938.*

Variety	Treatment	Germination, %	Weak, %	Dead, %	Height of strong plants in 14 days, ins.	Height of weak plants in 14 days, ins.
Alaska	Untreated (original)	96.0	4.0	0.0	5.5	2.0
	Lightly rubbed	95.0	4.5	0.5	5.5	2.5
	Heavily rubbed	95.5	4.5	0.0	5.5	2.0
Cartier	Untreated (original)	91.5	7.0	1.5	5.0	2.0
	Lightly rubbed	93.0	6.5	0.5	5.0	2.0
	Heavily rubbed	94.0	4.5	1.5	5.5	2.5
Minota	Untreated (original)	93.5	4.5	2.0	4.5	2.0
	Lightly rubbed	93.0	6.5	0.5	4.0	1.5
	Heavily rubbed	94.0	4.0	2.0	4.0	2.0
Columbia	Untreated (original)	95.0	1.5	3.5	5.0	1.5
	Lightly rubbed	95.5	2.0	2.5	5.5	2.0
	Heavily rubbed	95.0	3.0	2.0	5.5	2.0
Markton × Idamine (C. I. No. 2570)	Untreated (original)	89.0	4.0	7.0	4.5	2.0
	Lightly rubbed	88.5	6.5	5.0	5.0	2.5
	Heavily rubbed	91.0	5.0	4.0	5.5	2.5
Gopher A	Untreated (original)	83.0	7.0	10.0	4.0	2.0
	Lightly rubbed	89.5	3.0	7.5	4.5	2.0
	Heavily rubbed	82.5	3.5	14.0	4.0	2.0
Gopher B†	Untreated (original)	66.5	10.0	23.5	4.0	2.0
	Lightly rubbed	66.0	8.5	25.5	4.0	2.0
	Heavily rubbed	73.5	9.0	17.5	4.0	2.0

*Seven samples.
†Samples slightly musty when rubbed and stored.

The seed is the same as was grown and rubbed in 1935. It was stored for 2 years, however, before being tested.

Two hundred seeds were picked at random from each of the untreated (original), lightly rubbed, and heavily rubbed samples and planted in soil in flats in the greenhouse in January. The soil was kept

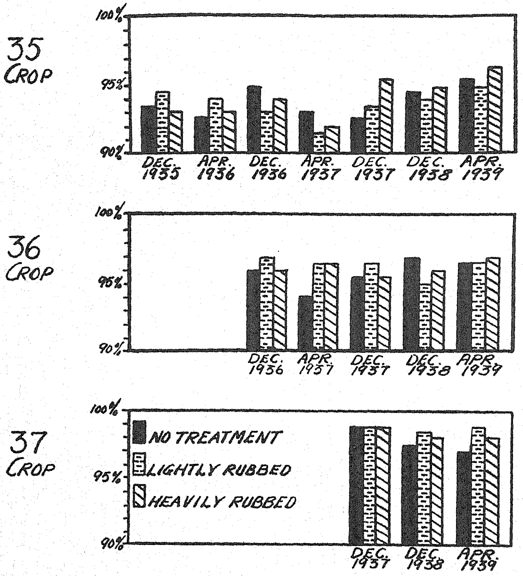

FIG. 2.—The relative germinability of untreated, lightly rubbed, and heavily rubbed oat grains of the Cartier variety from the 1935, 1936, and 1937 crops, respectively.

well wet down during the entire period of germination and growth. The temperature of the air in the greenhouse was kept at about 60° F. It will be apparent that the conditions under which these tests were conducted were not especially favorable and might even be said to approximate those under field conditions. It will be noted too that the seed had been stored for 2 years.

The results of the greenhouse tests in soil are not different from those made in the germinator. It is clearly seen that the lightly rubbed and heavily rubbed seed have in all instances germinated quite as

well as the untreated seed. Furthermore, additional evidence is here afforded on the number of weak and dead seeds present, also on the subsequent growth and vigor of plants as measured by the height of the plants, from both the strong and weak plants. From these rather limited data, it will be noted that there is no measurable difference in the viability of the untreated and the rubbed grain.

SUMMARY

The grain of six varieties of oats was treated (lightly and heavily rubbed) to remove tips or tails of the hull and other extraneous materials. Test weight and viability tests were conducted.

The test weight was increased on the average from 21.8 to 37.4%, or 7.3 to 10.2 pounds per bushel. The higher percentages occurred in the lighter weighing samples.

The germination tests carried out in the Minnesota germinator and in soil in the greenhouse showed no indication of loss in viability of the seed that was traceable to the rubbing or clipping. These results were consistent in all samples stored for periods ranging from 4 months to more than 3 years duration.

GROUND RAINFALL UNDER VEGETATIVE CANOPY OF CROPS[1]

J. L. HAYNES[2]

THE influence of vegetative canopy on character and amount of ground rainfall has been found to affect the non-capillary porosity, percolation rate value, and particle arrangement and coherence as reported by Hendrickson (2),[3] Neal (5), Lowdermilk (4), and Wollny (6, 7) in studies relating to impaction, soil percolation, and effect of vegetative cover. The amount of ground rainfall directly affects the amount of moisture available for plant use as well as potential supply of water contributing to run-off. Distribution of ground rainfall beneath the vegetative cover affects the local availability of water to the roots and influences turbulence of flow and character of drainage pattern during run-off. Detailed descriptions of the character of ground rainfall are needed in development of methodology of hydrograph analysis where run-off from different vegetative covers are considered.

Investigations of the character of ground rainfall under forest canopy were made by Horton (3) in 1919, but determinations of character of ground rainfall under crop cover have been inadequate to meet the needs of certain phases of present development in applied hydrology.

Results reported herein show measurements of the components of ground rainfall over a period of 3 years of study. Records for the 1937 growing season, taken at Bethany, Mo., under alfalfa, oats, corn, and soybeans, and for selected periods under timothy, bluegrass, and wheat, have been reported in mimeographed form (1). The study was carried forward during 1938 and 1939 at Sussex, N. J., for the crops of alfalfa, oats, corn, clover (Ladino), timothy, and bluegrass for the entire growing season.

PROCEDURE

The character of ground rainfall is such that it does not readily lend itself to accurate measurement. Specialized equipment, therefore, had to be developed for purposes of the investigation.

Canopy penetration was measured separately from stem water, both because it is difficult to measure these components simultaneously with a single catchment basin and because the effect of the two components upon ground rainfall impaction and distribution is notably different. Water running down the plant stalks was diverted into catchment basins by means of a funnel-like collar sealed to the stem by wax.

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[1]Joint contribution from the U. S. Soil Conservation Service, Office of Research, and the New Jersey Agricultural Experiment Station, New Brunswick, N. J. Also presented at the annual meeting of the Society held in New Orleans, La., November 22, 1939. Received for publication November 23, 1939.

[2]Junior Soil Conservationist, Soil Conservation Experiment Station, Sussex, N. J.

[3]Figures in parenthesis refer to "Literature Cited", p. 184.

Canopy penetration under corn was measured by means of galvanized metal pans 4 inches deep and 42×42 inches wide which were placed between the drill rows.

Canopy penetration under all crops except corn was measured by means of a series of V-shaped copper troughs 24 inches long, $1\frac{3}{64}$ inches wide, and 1 inch deep, which were placed on the ground beneath the plants. The catchment gages discharged into buried concentration units where the catch was measured.

Under mass crops, distribution of ground rainfall was measured with a gage consisting of concentric collecting units, while under row crops it was measured with parallel units. The collecting units were spaced at uniform distances from the stem for individual plants and from the drill row for row crops.

During two of the three years of record, intensity recorders were installed to receive flow from canopy penetration and stem water catchment units. In order to check consistency of results canopy penetration gages were installed in duplicate on all crops and stem water installations in triplicate during the last year of records.

Examination of records from the replicated installations showed that canopy penetration measurements checked very closely. Stem water measurements, on the other hand, were extremely erratic, so much so that it is apparent that a block involving a considerably larger number of this type installation would be necessary to obtain an exact quantitative measurement of the stem water. A part of the error involved in measuring the stem water may have resulted from the practice of attaching measuring equipment only to sturdy individuals. Intensity records from stem water attachments showed the shape of the intensity curve, but in general the amounts recorded were obviously in excess of the average for field conditions. These curves will be presented at a future date in connection with problems related to hydrograph analysis. In view of the erratic nature of the stem water measurements these are presented separately from canopy penetration figures which latter were consistent in replication. Intensity records presented herein were selected from records of small storms where the contribution of stem water to ground rainfall was minimized.

Quantative measurements of vegetative cover were made by use of pantograph and planimeter. As used in this discussion, density measurements are expressed as unit of ground area divided into the plant surface above it, considering the area of one side of all leaves and the entire stem surface. Thus a crop having a density of 6.0 would bear 6 square feet of plant surface per square foot of ground surface. Foliage cover, sometimes termed ground cover, is expressed as percentage of ground surface covered by the projected crop canopy. A stand having 75% foliage cover would thus shade three-fourths of the ground at high noon.

RESULTS AND DISCUSSION

A summary of ground rainfall measurements for all the crops which were studied appears in Table 1. It will be noted that the mass crops, bluegrass, clover, timothy, and alfalfa, indicated relatively smaller amounts of ground rainfall than did row crops. The records for 1937 were taken at Bethany, Mo. The 1938 and 1939 records were collected at Sussex, N. J. It should be pointed out that records of stem water, when collected, frequently indicated negative results of interception for individual storms. At the initial stages of the experiment, wax-floored catchment basins were placed under oats,

bluegrass, and timothy for the purpose of determining whether significant amounts of water reached the ground by passing down the stem. During the period of these tests no rains exceeding 0.50 inch were recorded, and the equipment showed no stem water during this period. However, when intensity records of subsequent rainfall in excess of 0.50 inch are plotted, there are definite indications that these crops do pass water to the ground via the stem. For this reason percentages shown which exclude stem water measurements are in excess of the total ground rainfall to be expected under field conditions.

Data for all storms, regardless of size or stage of crop growth, are included in the results shown in Table 1. These represent full growing season records for alfalfa, corn, clover, soybeans, and oats. Full growing season records for bluegrass are included in the 1938 and 1939 results. Results for 1937 under bluegrass and timothy represent storms during the month preceeding harvest of the respective crops. Records for timothy during 1938 and 1939 were discontinued at the date of the first harvest of the crop.

TABLE 1.—*Precipitation and ground rainfall records during the respective experimental periods for each crop studied.*

	Year	Alfalfa	Corn	Clover	Bluegrass	Oats	Timothy	Soybeans
Precipitation, in.	1937	12.31	7.12	—	0.98	6.77	1.11	6.25
	1938	32.82	12.82	23.21	29.65	12.39	10.93	—
	1939	11.99	6.93	11.08	11.99	3.15	3.94	—
Total inches		57.12	26.87	34.29	42.62	22.31	15.98	6.25
Canopy penetration, in.	1937	7.25	4.84	—	0.82	6.34	0.82	4.06
	1938	21.23	9.10	14.00	13.76	9.08	6.58	—
	1939	8.48	4.95	7.93	4.62	2.53	3.17	—
Total inches		36.96	18.89	21.93	19.20	17.95	10.57	4.06
Stem water, in.	1937	0.76	1.18	—*	—*	—*	—*	1.28
	1938	5.84	3.18	—*	—*	—*	—*	—*
	1939	1.24	1.76	—*	—*	—*	—*	—*
Total inches		7.84	6.12	—	—	—	—	1.28
No. of observations		125	51	69	73	69	43	18
Total interception, including stem water, % of rainfall		21.6	6.9	—*	—*	—*	—*	14.6
Total interception, excluding stem water, % of rainfall		35.3	29.7	36.0	55.0	19.5	33.9	35.0

*No stem water records taken.

Distribution of ground rainfall under row crops is illustrated by records from soybeans shown in Fig. 1. It will be noted that more than twice as much precipitation falls in the center of the interspace than adjacent to the row. Stem water is not considered in this graph. The

canopy apparently tends to pass precipitation from leaf to leaf in a shingle effect toward the interspace. This tendency was pronounced even after the vegetation covered the entire interspace. A similar character of distribution of ground rainfall was found under drilled oats. When wind direction during the storm was at right angles to the row direction, a concentration of ground rainfall was recorded on the leeward side of the interspace.

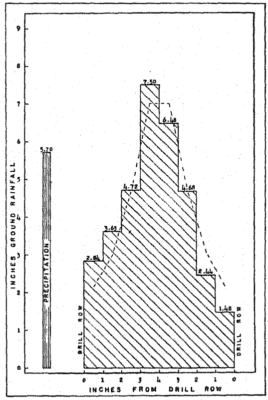

FIG. 1.—Distribution of ground rainfall between drill rows of soybeans. The dotted line represents average distribution in the interspacing.

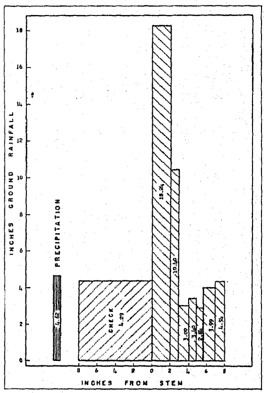

FIG. 2.—Distribution of ground rainfall under single alfalfa plant.

Distribution of ground rainfall under a single plant is illustrated by alfalfa, results of which are shown in Fig. 2. This graph includes stem water flow in the unit adjacent to the stem. The higher precipitation shown in the outer units probably represents the shingle effect of canopy upon rainfall, which was shown under drilled crops. Results from individual storms indicated more ground rainfall on the windward side of the plants. The edge of the canopy was limited to an 8-inch radius from the stem.

An increase in percentage of interception was noted with increase of vegetative growth. Fig. 3 shows interception by 10-day periods previous to harvest dates for the crops under study. Storms having less than 0.05 inch precipitation were excluded from figures used in compilation of these curves. Measurements of stem water were also omitted in order to make the curves for each crop comparable.

Ground rainfall intensities under various crops selected from small storm periods are shown in Fig. 4. Intensity of ground rainfall fre-

quently exceeds the actual rainfall during the periods following high precipitation intensities. Peak precipitation intensities tend to be lowered by vegetative canopy which spreads the amount of rainfall

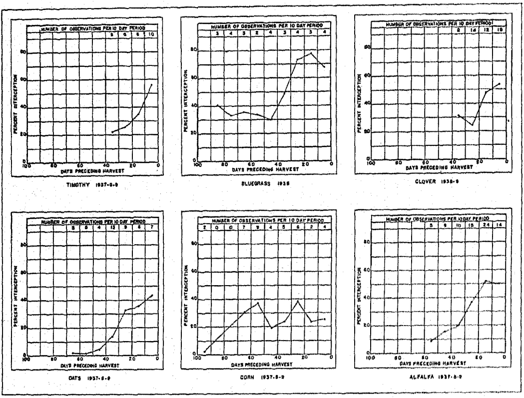

FIG. 3.—Relationship of amount of canopy penetration to vegetative development for various crops.

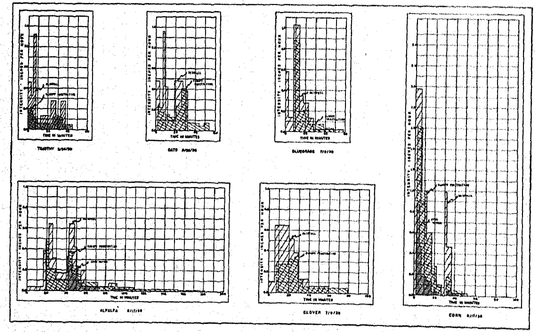

FIG. 4.—Intensity of rainfall, canopy penetration, and stem water under crops from selected storm periods during maximum vegetative development. Solid lines represent rainfall, dotted lines show canopy penetration, and broken lines show stem water.

over a longer time period by detention on the vegetative cover. It is pointed out, however, that localized spots beneath the canopy experience considerably higher intensity rates than is caused by the actual precipitation. This localized increase of intensity is dependent entirely upon the character of plant growth which, according to the nature of the plant, may concentrate ground rainfall at the stem or at the edge of individual plant canopies. In this relationship it is to be kept in mind that impact of rainfall is normally broken by vegetative canopy before reaching the ground even at points of high ground rainfall concentration.

ALFALFA

Alfalfa used in this study was managed as hay, being harvested at 18 to 20 inches when the plants started to bloom. Average density of cover by planimeter readings was 7.0 at stages of maximum vegetative development. During certain types of storms, precipitation finds a resting place on both sides of the leaf, in which case a plant surface equal to almost twice the density figure named is potentially available to interception storage and, obviously, to evaporation exposure. Foliage cover reached 90 to 100% before cuttings.

Interception immediately following mowing was relatively small, increasing with vegetative growth following cutting, as shown in Fig. 3. Intensity records from canopy penetration measuring equipment showed higher percentage of interception at the initial stage of the storm but that interception storage is not necessarily completed at the start of ground rainfall. It will be noted from Fig. 4 that a considerable amount of water reaches the ground by passing down the stem, even during the low intensity storm selected for this graph.

CORN

Corn under which ground rainfall measurements were made was in 42-inch drill rows, with average 14-inch hill spacing for the 1937 records and 9-inch spacing for the 1938 and 1939 records. Density and foliage cover were somewhat greater than measurements from comparable stands of checked corn.

Corn reached a height of 3 feet before rainfall in measurable quantities was intercepted by the crop canopy. At the period of maximum vegetative development, corn had 55 to 65% foliage cover, density of 2.4, and a height of 8 feet. As leaves matured and broke toward the end of the season, foliage cover was reduced. The plant surface of corn, as compared with alfalfa, is not well distributed over the ground due to the character of the vegetative growth.

The amount of water reaching the ground by following the corn stalk is relatively large. This in part accounts for the irregularity of the curve of seasonal interception shown in Fig. 3 which does not include stem water measurements. Records from canopy penetration measuring equipment showed a higher percentage of interception at the initial stage of the storm but showed also that interception storage is not necessarily completed at the start of ground rainfall. As shown in Fig. 4, a considerable amount of water reaches the ground by passing down the stem. Frequently stem water flow started considerably

in advance of canopy penetration catch. The nature of the final stage of the storm period appears to have considerable effect on the total interception.

SOYBEANS

Soybeans were drilled in 8-inch rows. At maximum vegetative development they reached a density of 4.2, a foliage cover of 95%, and a height of 38 inches during the single year of observations. Approximately one-third of the precipitation was conducted to the ground by the stem when the plants had reached full maturity. Intensity of canopy penetration seldom equalled that of actual precipitation.

OATS

Oats, under which interception measurements were made, were drilled in 8-inch rows. At maximum vegetative development measurements showed a density of 11.6 and foliage cover of 55 to 65%. Although density of vegetative cover is high, the bulk of plant surface is concentrated in the drill rows leaving considerable areas of exposed ground in the interspace. Intensity of ground rainfall under oats frequently equals that of precipitation during prolonged storm periods.

Measurements of canopy penetration under wheat during a 30-day period immediately preceeding harvest showed 19.9% interception which compares closely with the longer period recorded under oats.

TIMOTHY

Timothy reached a maximum density of 17.3, foliage cover of 80 to 95%, and height of 25 to 35 inches during the course of study. A large portion of the plant surface is limited to the region of the plant stem although the ground surface is generally well covered by leaf area as indicated by the high foliage cover. Measurements of interception under timothy made at intermittent periods subsequent to harvest showed negligible interception until fall growth. Timothy was harvested in June during this period of study.

BLUEGRASS

Bluegrass used in the 1937 measurements did not include ground litter. Maximum foliage cover was 25%. The catchment units were placed beneath the grass litter for the 1938 and 1939 studies. The crop was harvested in June during 1938 and was allowed to grow rank without cutting for the 1939 season during which time the grass reached a length of 18 inches and lodged 10 inches over the equipment. Measurements made at the time of most heavy growth in 1939 showed a density of 12.9, including the fallen blades which made up the ground litter and 100% foliage cover.

CLOVER

The clover under which measurements were made was a dense stand of Ladino, a mammoth white clover. The stand reached a maximum height of 24 inches in 1938 and 16 inches in 1939. The growth

recovery following harvests was rapid, normally providing a complete foliage cover within 3 weeks. No density measurements were made on this crop.

SUMMARY

It is obvious that vegetative canopy may influence soil and water losses in four ways, namely, by alteration of intensity of ground rainfall, by alteration of total amount of water available to carry silt load, by alteration of impact, and by character of distribution of ground rainfall.

It is likewise apparent that water which reaches the ground by passing down the stems will exert less impact than that which falls from the canopy, and, in turn, that canopy penetration will have less impact than actual precipitation. The functions of vegetation as obstruction to overland flow are not considered in this discussion.

Of the crops studied, water reaches the ground under mass crops with less potential energy for moving soil than under row crops. Reduction of total ground rainfall is greater, intensity of ground rainfall is less, energy of initial impact is lessened, and distribution of ground rainfall is fairly uniform, except for greater volumes at the stem and at the periphery of individual plant canopies under mass crops than under drilled crops. Because of the large number of stems per unit area of mass crops, the stem water is better distributed over the ground surface than under corn, for instance.

Amount of canopy penetration under corn at maximum vegetative development is reduced from that of actual precipitation. Since a relatively large amount of direct precipitation reaches the ground, impact is considerably higher than under alfalfa. The large amounts of stem water would be expected to influence soil and water losses, evidence of which has been observed in the field in the form of rivulets on either side of the corn rows drilled up and down the slope.

Intensity of canopy penetration under oats and soybeans is reduced, although total ground rainfall approaches that of actual precipitation. Impact is much reduced after the crop has reached full vegetative development. In distribution, ground rainfall tends to concentrate water between the rows, thus promoting turbulence of flow in the interspace.

CONCLUSIONS

1. Measurements of ground rainfall under various crop canopies have been made over a 3-year period of study.
2. Interception was found to increase directly with vegetative cover.
3. Intensity of ground rainfall is in general less than that of actual precipitation.
4. Distribution of ground rainfall is influenced by the character of vegetative growth.
5. A portion of ground rainfall under crops having stems or stalks is conducted to the ground by the plant stem.
6. Foliage cover, density, height, and character of vegetative growth appear to contribute to the effect of vegetative canopy on character and amount of ground rainfall.

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THE WELFARE OF CATTLE ON FLORIDA PASTURES[1]

R. B. Becker and J. R. Henderson[2]

LIVESTOCK in the bluegrass region of Kentucky, the Shenandoah Valley of Virginia, and parts of England are world famous for their excellence from many standpoints. Animals thrive in those regions because the forages grown on the soils contain optimum amounts of the nutrients essential to the welfare of animal life. In other regions, the development of livestock depends somewhat upon the degree that the soil has limited the level of some essential element in the forages utilized as feed. The fact that fertility of the land limited the thrift of livestock in any particular region was recognized generations ago by the early agricultural writers.

In 1776, John Mills (16)[3] attributed to mismanagement more than to infertility the stinted size of some of the farm stock of England.

William Aiton (1) associated the kind of soil with thrift of the cattle of southwestern Scotland.

Even on the Island of Jersey, LeCouteur (13), Secretary of the Royal Jersey Agricultural and Horticultural Society, observed that, "In so small a spot as Jersey, it is difficult to cross the breed essentially—a great step towards it is gained by crossing cattle bred in the low rich pastures with those of the exposed hills on the western or northern coasts: these being smaller, finer boned, of a more hardy constitution, and feeding on a short rich bite, impart strength of constitution and hardihood to the larger and more delicate animals of the sheltered low grounds."

Two of the leading authorities on livestock a century ago were David Low, Professor of Agriculture in the University of Edinburgh, and William Youatt of England. Low (14) wrote that, "It is upon the supply of food that the size of the animals seems mainly to depend. Wherever food is supplied in abundance, the ox becomes enlarged in bulk; and wherever food is deficient, whatever be the nature of the climate, his size becomes less."

Youatt (19) wrote in the same vein as follows: "The breeds of cattle, as they are now found in Great Britain, are almost as various as the soil of the different districts, or the fancies of the breeders. ....Thence it resulted, that in Devon, in Sussex, in Wales, and in Scotland, the cattle have been the same from time immemorial; while in all the eastern coast, and through every district of England, the breed of cattle degenerated, or lost its original character; it consisted of animals brought from every neighboring and some remote districts, mingled in every possible variety, yet conforming itself to the soil and climate."

The above-mentioned writers dealt with areas usually considered adequate for the production of cattle. At the other extreme, on defi-

[1]Contribution from the Florida Agricultural Experiment Station, Gainesville, Fla. Also presented at the annual meeting of the Society held in New Orleans, La., November 22, 1939. Received for publication November 23, 1939.

[2]Dairy Husbandman and Assistant Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 188.

nitely deficient areas, infertility of the soil limits the composition of the grass in some essential element to the extent that the thrift of livestock is affected to a greater degree.

Thus, Hogg (12) wrote of an anemia called "pining" among sheep on the northern slope of the Cheviot Hills on the Scottish border. An unnamed writer (2) in the same issue of the *Quarterly Journal of Agriculture* stated that pining increased especially on astringent pastures such as those on the syenitic porphyry of the Cheviots, and that it is not known on the clay slate range of the Lammermuir Hills, nor is it found on heath or green pastures on a calcareous (red) sandstone formation.

McGowan and Smith (15) studied the same area a century later, and observed the practice of the stockmen to change to new pasturage once or twice in the year. It was a common belief that otherwise the whole stock would die out in less than two years if they were kept constantly on the same ground.

The virgin fertility of a pasture soil is related directly to the welfare of the cattle grazing thereon. The kind and amount of plant food available in a virgin soil determine both the kind and amount of native forages produced. This is particularly true on certain virgin soils of the coastal plains in the southeastern states.

In the spring of 1930, before mineral supplements were used generally in Florida, Camp (10) studied 7,100 head of cattle on 110,000 acres of range and pasture land, including all of the native cattle then in one county in herds of over 50 head. The records were sorted into four groups in relation to the types of native pasture over which the cattle grazed. The pasture types were designated as flatwoods (mainly palmetto flatwoods), deep sandy or blackjack lands, the wet prairie soils high in organic matter, and hardwood hammock lands. The soils represented in these several types of pastures were as follows:

Flatwoods—Leon, Portsmouth, and Plummer fine sands
Blackjack—Deep phase of Norfolk fine sand
Prairie —Bayboro fine sandy loam and Bayboro loamy fine sand
Hammock—Fellowship, Hernando and Gainesville fine sandy loams and Fellowship clay loam.

By actual counts of cattle at the dip vats and by interviews with individual owners, Camp obtained records concerning the numbers of calves produced, raised, and marketed per hundred breeding cows, and the market returns per animal sold. These records were analyzed to determine the gross returns per breeding cow on each class of range (Table 1).

Undoubtedly a number of other factors besides soil type were involved in the returns. The class of pasture and all that is associated with it was the largest contributing factor involved. The soil and moisture supply affected the type of native grazing crop, its amount over the grazing period, the composition of the forage, and the efficiency of its utilization by the cattle.

Information supplied to the senior author during 1929 and 1930 by cattlemen over a wider area was substantiated by Camp's observations. The nutritive value of the native vegetation growing on certain

TABLE I.—*Returns per breeding cow on different types of range in Florida.*

Range	Average calf crop, %	Animals marketed, %	Average value at 2½ years*	Gross annual return per breeding cow
Flatwoods....	34.4	34.20	$30.20	$10.33
Blackjack....	37.1	35.61	23.75	8.46
Prairie.......	54.1	53.80	35.50	19.10
Hammock....	70.6	71.60	36.50	26.13

*Mostly sold as butchered beef.

soils limited the number of calves produced, the number that survived, the ability of the dams to provide milk, and the resulting weight and grade of the calves at market age. At the same time, dairymen located on some types of land were quite successful in raising calves, while on other areas the losses of calves were so great that other dairymen there had ceased trying to raise their own replacements. The fencing of pastures and restricting the soil type over which cattle grazed aggravated the condition.

An investigation of the cattle on the various classes of pasture lands led to integration into a number of problems, some occurring separately and others overlapping one another. Several of these causes are as follows: (a) Inadequate intake of calcium; (b) inadequate intake of phosphorus; (c) inadequate intake of iron, or of iron and copper; and (d) inadequate intake of cobalt, iron, and copper, or a combination of these with low cobalt.

Inadequate calcium intake (3, 6) was seen among Jersey cows that were fed silage and hay grown on quite acid Alachua fine sand, Norfolk fine sand, and Arredonda fine sand.[4] The correction of this condition by the use of feeding bonemeal, and more recently by a combination of bonemeal and marble dust (calcium carbonate), was accompanied by greater strength of bones and a marked response in milk yields.

Inadequate phosphorus intake (7, 9) was seen among farm cows and range cattle subsisting entirely on native plants growing on Norfolk, Ruston, and Orangeburg fine sandy loams in one area and on Leon and Plummer fine sands in another. Fractured bones and depraved appetites were encountered among cows under such conditions. Cattle receiving phosphorus supplement in the form of bonemeal ceased chewing bones, leather, wood, etc., and tended to fatten under conditions which hitherto had caused them to remain spare or thin.

Inadequate quantities of iron, copper, cobalt, or combinations of these in the forage have been observed to restrict growth and welfare of livestock on several types of soils (5, 8, 17).

Anemic cattle on one pasture occupying a river terrace on which the dominant soil is Kalmia fine sand recovered when supplied only a commercial grade of ferric ammonium citrate. On other pastures of Leon fine sand and the flat phase of St. Lucie fine sand, particularly, responses of dairy heifers, family cows, and range cattle were de-

[4]Alachua and Arredonda are tentative series names.

layed until copper sulfate was added to the ferric ammonium citrate in a ratio of 1 part of copper to 50 parts of iron.

A supplement called "salt sick" mineral was used commercially over the state in two mineral mixtures. The second formula, with a reduced amount of salt, was used with cattle close to salt marsh or brackish water areas. The formulas were as follows:

	No. 1	No. 2
Common salt	100	50
Bonemeal	None	50
Red oxide of iron	25	25
Pulverized $CuSO_4$	1	1

At the Florida Experiment Station, controlled feeding trials were conducted using separate pure minerals to supplement Natal grass hay and corn grown on a light Norfolk fine sand. Jersey calves in these trials ceased growth when 5 to 8 months old. Only one calf thrived with the iron-copper supplement until, following a clue from Australia (4, 11, 18) traces of a cobalt salt were added to the ration by Dr. W. M. Neal (17).

Reports of failures of livestock to respond to the use of "salt sick" mineral No. 1 were received from stockmen having cattle on deep Norfolk fine sand in certain areas, Lakewood fine sand, Leon fine sand, Blanton fine sand, and on one area of muck. Addition of an ounce of cobalt sulfate to the No. 1 iron-copper supplement used on these areas was accompanied by prompt responses by cattle, goats, and swine under observation in these cooperative field investigations.

Thus it is seen that cattle dependent on the forage grown on any definite area are limited in their development and activity according to the amounts of certain minerals contained in that forage. A full understanding of the limitations of the soils within the available pasture areas in supplying these minerals places the stockman in a position to use the correct supplements in his stock feed or mineral mixture, or to manage his soils in such a way that these minerals may be obtained from the forage produced thereon.

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RUSSIAN THISTLE SILAGE[1]

F. T. DONALDSON AND KENNETH J. GOERING[2]

SINCE its introduction into South Dakota about 1873 (8),[3] the Russian thistle (*Salsola pestifer* Aven Nelson) has become widely distributed in the United States and Canada. Due to its high drought resistance, it flourishes in semi-arid regions and during abnormally dry years is often the only plant available for emergency feed.

The value of the Russian thistle for pasture or for hay depends in a large measure upon the maturity of the plant when it is grazed or cut. The young plant is quite succulent and contains a high percentage of protein; but as the plant matures hard, spiny tips develop, the percentage protein decreases (10, 4), and the stems become hard and fibrous. The possibility of preserving the young succulent plants by ensiling was suggested to the authors[4] and this paper constitutes a report of laboratory trials on several types of Russian thistle silage.

The small amount of silage which can be prepared in laboratory trials limits the usefulness of the data which can be obtained from such tests. Naturally no feeding tests can be conducted and little information can be obtained which will determine the value of the process from an economic viewpoint. The object of this study, however, was to determine the possibility of preserving the immature plants in a palatable state. Such an objective involves a study of the chemical characteristics of the silage, and it has been demonstrated that laboratory trials are adequate for this purpose (1, 3).

CHEMICAL COMPOSITION OF RUSSIAN THISTLES

The Russian thistles used in this study were cut on August 27. The spines on this date were just starting to feel prickly but were still fairly soft. Representative samples containing approximately 80% moisture were analyzed for the usual feed values and also for minerals. The results of these analyses are listed in Table 1. For comparison, the average values obtained from the analyses of 89 samples of Montana-grown alfalfa (7) are also included in the table.

The analyses show that the young thistles are equal to the alfalfa in protein and ether extract content and have a more favorable carbohydrate-crude fiber balance. This apparent superiority may be offset by the high potash content which is the probable cause of the laxative effect of the thistles. In view of the apparent phosphorus deficiency in certain Montana forages, the high P_2O_5 content of the thistle may enhance its value as a feed.

PREPARATION OF SILAGE

Due to the high protein and high ash content of the thistles, it was

[1]Contribution from the Chemistry Department, Montana State College, Agricultural Experiment Station, Bozeman, Mont. Paper No. 110, Journal Series. Received for publication November 29, 1939.

[2]Assistant Professor and Assistant Chemist, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 193.

[4]This work was carried on at the suggestion of Mr. Edmund Burke, Chemist, Montana Agricultural Experiment Station.

considered unlikely that silage prepared without the addition of some acid or acid-forming substance would be successful. Hydrogen-ion concentration is the prime factor in the successful preparation of silage and in order to develop the required acidity, the crop must possess a relatively high carbohydrate-protein ratio. During the last decade considerable progress has been made in the preservation of high protein forage crops by ensiling with an acid or with some material rich in fermentable carbohydrates (11, 9, 2). Wilson (14) has determined what are essentially the relative buffer capacities of various plant materials and found that high protein materials require more acid per unit pH change than low protein material.

TABLE 1.—*Chemical analyses of Russian thistles and alfalfa hay, dry basis.*

Constituent	Russian thistle, %	Alfalfa, %
*Feed Analyses**		
Crude protein (N × 6.25)	16.2	16.5
Ether extract	1.7	1.5
Crude fiber	20.7	33.4
Ash	19.5	8.7
Nitrogen-free extract (by difference)	41.9	33.9
Mineral Analyses†		
CaO	1.84	2.02
MgO	1.93	0.48
SO_4	0.84	—
P_2O_5	0.78	0.42
K_2O	8.25	—
R_2O_3	0.55	—
Siliceous matter	0.42	—

*Analyses of sample of Russian thistle used for making silage and average of 89 samples of alfalfa hay.
†Analyses of sample of Russian thistle used for making silage and average of 10 samples of alfalfa hay.

The Russian thistles were cut into pieces ½ inch long or less and packed as tightly as possible into ½ gallon jars holding approximately 1,400 grams of the green chopped material. Three types of silage were prepared. The first was prepared with thistles plus 3% sucrose, the second with thistles alone, and the third with thistles plus 1% H_3PO_4. Escape valves were provided on all the jars to prevent the intake of air. The jars were left in the laboratory (about 22° C) for 7 months when they were opened and the silage analyzed.

None of the three types of silage appeared to be spoiled, but the silage made without the addition of a preservative was darkest in color and possessed a sharper odor of acetic acid than did the other two.

ANALYSIS OF SILAGE

The silage was ground in a Nixtamal mill and water extracts were made according to the method of Woodman (15). The pH was determined with a glass electrode and sugars by the alkaline ferricyanide method (5). Volatile bases, amino acid, total acidity, and

volatile and non-volatile organic acids were determined by Woodman's (15) modification of Foreman's (6) method. The results of these analyses are given in Table 2.

TABLE 2.—*Analyses of Russian thistle silage prepared in three different ways, wet basis.*

Constituent	Thistles plus 3% sucrose	Thistles untreated	Thistles plus 1% H_3PO_4
pH of expressed juice	3.95	4.78	4.05
Volatile organic acids as % acetic	0.38	0.47	0.33
Non-volatile organic acids as % lactic	2.08	0.87	2.09*
Ratio non-volatile organic acids to volatile organic acids	5.5	1.9	6.4*
Amino acids as % crude protein	0.78	0.90	0.56
Volatile bases as % crude protein	0.31	0.33	0.20
Total nitrogen as % crude protein	3.29	2.94	2.99
Volatile base nitrogen as % of total nitrogen	9.4	11.3	6.8
Amino acid nitrogen as % of total nitrogen	23.7	30.6	18.6
Volatile base plus amino acid nitrogen as % of total nitrogen	33.1	41.9	25.4
Ratio amino acid nitrogen to volatile base nitrogen	2.6	2.7	2.7
Dry matter, %	20.7	17.1	17.0
Total sugar as % invert sugar	1.84	0.37	0.35

*These values include the added H_3PO_4. Correcting for the H_3PO_4 gives a value of 0.54% lactic acid.

DISCUSSION OF RESULTS

ACIDITY AND PH

It has been demonstrated that pH of silage is the best single indication of quality (13). Above a pH of 4.2 there is an increasing tendency for the butyric acid type of fermentation to take place with its accompanying chemical changes which lead to putrefaction. A pH of 4.78 for the untreated silage indicates that this material came dangerously close to spoiling. The pH values for the other two types are satisfactory and show that they were preserved with some margin of safety.

As might be expected, the sugar silage contained the largest amount of lactic acid and had the highest ratio of non-volatile to volatile organic acids. A high value for this ratio indicates good quality silage, for lactic acid is a stronger acid than either acetic or butyric and produces a higher hydrogen-ion concentration in the silage. When an inorganic acid is added, the lactic-acetic acid ratio is not necessarily indicative of quality, for in this case the silage is brought rapidly to a low pH value by the inorganic acid, and large amounts of lactic acid are no longer required to prevent the butyric acid type of fermentation.

VOLATILE BASES AND AMINO ACIDS

Even in good silage a surprisingly large proportion of the protein undergoes varying degrees of breakdown. Most of the decomposition products are either volatile bases or amino acids and hence determinations of these two types of compounds afford a reliable measure of protein decomposition. It is probable that the formation of amino

acids involves little loss in feeding value, but it is questionable if volatile bases are of much value (12). Volatile base formation was greatest in the untreated silage and least in the acid silage, showing the effectiveness of the acid in checking protein decomposition. This is shown even better by the data giving the sum of the amino acid and volatile base nitrogen as percentage of total nitrogen. In the untreated silage 41.9% of the total nitrogen was present as volatile bases or amino acids, while in the acid silage these decomposition products represent only 25.4% of the total nitrogen. The figure for sugar silage is somewhat higher than that for acid silage, indicating that the acid treatment is more effective in preventing protein decomposition. Although Watson and Ferguson (12) have shown that the amino acid nitrogen is equivalent in nutritive value to the true protein nitrogen in the diet of the dairy cow, it must be realized that excessive formation of soluble amino acids may result in losses through the juice which drains from a silo.

SUGARS

Only small amounts of sugars were present in the untreated and acid silage, but the sugar silage contained 1.8%. This indicates that the 3% sucrose added was considerably in excess of the amount necessary for adequate lactic acid production. In actual practice the sugar necessary to preserve high protein material is usually added in the form of molasses.

SUMMARY

1. Analyses of Russian thistles showed these plants to be equivalent to alfalfa in protein and fat content and superior in their carbohydrate-crude-fiber ratio. The thistles had a high mineral content with the K_2O running over 8%. It was pointed out that the high P_2O_5 content (0.78%) may enhance the feeding value of the thistles in areas known to produce phosphorus-deficient forages.

2. In order to determine the possibility of preserving the immature plants in a succulent condition, laboratory trials were made of three types of Russian thistle silage. The first consisted of thistles plus 3% sucrose; the second, untreated thistles; and the third, thistles plus 1% H_3PO_4. Chemical analysis of the silage indicated that good silage could be prepared with the addition of either sugar or H_3PO_4, but that poor silage would probably result from the use of untreated thistles.

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STUDIES OF FRENCHING OF TOBACCO WITH PARTICULAR REFERENCE TO THALLIUM TOXICITY[1]

C. E. BORTNER AND P. E. KARRAKER[2]

STUDIES at the Kentucky Agricultural Experiment Station have been reported showing that frenching of tobacco is related to the reaction or lime content of the soil and to the soil nutrient supply (2, 8).[3] Later observations agree for the most part with these findings. There was considerable frenching in Burley tobacco on various plots of the Greenville soil experiment field in 1938, the extent depending on the plot treatment. The extent in various plots was determined on July 30. None was present on five unlimed plots, one of which had received no commercial fertilizer and the others varying nitrogen, phosphorus, and potassium treatments. The frenching on the plots which had received ground limestone and different commercial fertilizer treatments was as follows: Superphosphate, 40% (of the plants) severely frenched; superphosphate and nitrate of soda, 13% frenched to a medium degree; superphosphate and sulfate of potash, 6% frenched to a medium degree; superphosphate, nitrate of soda and sulfate of potash, 0.7% frenched to a medium degree; and superphosphate, nitrate of soda, and double the standard application of sulfate of potash, no frenching.

In one of the publications of this Station on frenching (2), it was stated that on the Campbellsville soil experiment field frenching occurred nearly every year on the limed plots and not on the unlimed plots, and that usually the frenching was much less severe where sulfate of potash was applied. Frenching still is entirely confined to the limed plots at this field and in many years is severe on these plots receiving only limestone and phosphate but much less severe on plots where potash has been applied in addition to limestone and phosphate.

Dr. E. M. Johnson, in field studies in western Kentucky in 1938 and 1939, observed frenching in 12 farm fields. In all but two, the pH of the soil in the frenched areas was 6.0 or above, that of the two exceptions being 5.53 and 5.58. Rapid soil tests showed a low supply of available phosphorus or potassium or both in all but one of the areas and the pH of the soil of this was 6.59. Potash deficiency symptoms were present at the time of frenching in over half the instances. The tobacco was Dark Fired, or One Sucker, except Burley tobacco in one field.

However, one clear instance has come to our attention of frenching where the soil was moderately to strongly acid. This was on a plot on the Experiment Station farm to which sulfur is added as necessary

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[3]Figures in parenthesis refer to "Literature Cited", p. 203.

to hold the pH of the soil at 5.0 or slightly below. The soil, Maury silt loam, is very high in calcium, a considerable part of which is present as the native calcium phosphate compound and a probable high calcium content of the soil solution may explain the appearance of the disease on this soil notwithstanding the low pH.

In 1932 McMurtry (4) suggested that frenching might be due to thallium toxicity. It did not seem likely to us that frenching was a toxicity disease in view of the reaction or liming and nutrient relationship found, and work was not done on this point at the time. In 1934, however, Turkish tobacco plants were grown in water cultures containing thallium. A toxic condition developed in some of the plants. This resembled frenching in certain respects but was unlike frenching in others and appeared to confirm our belief that thallium toxicity was not a cause of frenching. This experiment will later be referred to more fully.

In 1935, Spencer (5) stated that frenching probably was a toxicity disease; and in 1937 (6) that the experimental evidence reported "indicates a striking similarity between natural frenching and thallium toxicity."

Further studies by the authors on thallium toxicity and frenching and on certain other points appear to substantiate our belief that thallium toxicity is not related to frenching. The results of these studies were mentioned in the 1937 report of the Kentucky Agricultural Experiment Station and are reported upon more fully in this paper. After this manuscript was prepared, the paper of Spencer and Lavin (7) appeared in which it is stated that, on the basis of spectrographic analysis, the failure of field-frenched plants to contain any thallium suggests that frenching and thallium toxicity are different diseases.

WATER CULTURE STUDIES

In 1934 Turkish tobacco was grown in duplicate water cultures in quart Mason jars containing in different cultures 0.0, 0.5, 1.0, and 2.0 p.p.m. of thallium. Thallium was added as thallium nitrate in all the studies reported in this paper. Severe chlorosis and wilting of the plants occurred in all the cultures containing thallium. These plants did not recover when changed to cultures containing no thallium. Thallium at the rate of 0.1 p.p.m. was then added to each of the check jars. In 8 days, a yellow color developed along the veins and a bluish-green color between the veins in the leaves located about midway on the stalk, but the chlorosis did not resemble frenching.

Turkish tobacco was grown in a second water culture experiment in pint Mason jars in which the effect of a strongly acid and a slightly acid culture solution was tested on thallium toxicity and its relation to frenching. The pH values of the cultures were 4.5 and 6.2 and represent the pH of soils in which we have found (2) that tobacco, respectively, does not and does french. The pH was maintained by renewing the solutions every 2 or 3 days. The nutrient solution was 0.5 gram $Ca(NO_3)_2 \cdot 4H_2O$, 0.2 gram $CaH_4(PO_4)_2$, 0.12 gram K_2SO_4, 0.05 gram $MgCl_2$, 0.0005 gram H_3BO_3, 0.002 gram $MnCl_2$, and 1.0 cc saturated solution of ferric tartrate per liter.

In each of the pH series during the first part of the experiment, there were duplicate treatments of the following thallium concentrations: 0.00, 0.005, 0.010, 0.020, and 0.060 p.p.m. The plants were about 2 inches high when placed in the cultures on May 13. Chlorosis appeared on May 20 in the jars containing 0.06 p.p.m. of thallium in the pH 6.2 series, and 3 days later in the cultures of the same thallium concentration in the pH 4.5 series. No other chlorosis developed by June 4 when the plants averaged 16 inches high. They were cut back at this time and two suckers allowed to grow on each. (See Fig. 1.)

The thallium concentration was doubled in all cultures on May 30 and again on June 12, except that the 0.06 p.p.m. concentration was increased on May 30 to 0.08 p.p.m. and on June 12 to 0.10 p.p.m. From May 27 on, phosphorus was omitted from one jar in each dupli-

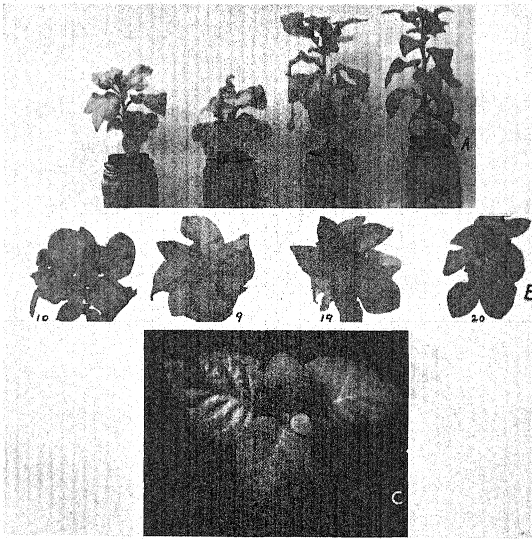

FIG. 1.—Plant grown in water cultures. A, jar 9, full nutrient pH 4.5; jar 10 phosphorus deficient nutrient pH 4.5; jar 19, full nutrient pH 6.2; jar 20 phosphorus deficient nutrient pH 6.2. Each culture received 0.100 p.p.m. of thallium. B, view of growing points on jars 9, 10, 19, and 20. C, Turkish tobacco showing the yellow-vein type of chlorosis. Plant grown in a culture (pH 6.2) containing 0.08 p.p.m. of Tl as $TlNO_3$; chlorosis was produced within 2 days. Photographed 18 days after treating.

cate treatment and from June 12 on was reduced one-half in the other jar; also on June 12 the other nutrients except iron were reduced one-half in all jars. It was thought these changes might favor the development of chlorosis because they have been found to have this effect on frenching.

None of the suckers were chlorotic when they first appeared, but chlorosis developed in all the 0.10 p.p.m. thallium cultures in the period June 12 to 18, the pH of the cultures having no effect in this connection. A mild chlorosis later developed in the 0.08 p.p.m. thallium culture containing phosphorus in each pH series. No chlorosis developed in the cultures containing no phosphorus. No other chloroses had developed by June 5 when the experiment was discontinued.

The first appearance of the chlorosis was a green-yellow mottling at the base of the leaf. This then developed into either a yellow vein with green interveinal tissue or a green vein with yellow interveinal tissue. The latter type appeared in the growing-point leaves and as they grew, changed into the former. When severe, the entire plant was yellow and in some instances strap-leaves were present.

The chlorosis in none of the plants fully resembled field frenching either as it first appeared or in the older chlorotic leaves. In all cases it started at the base of the leaf or along the midvein and moved toward the leaf tip and margin, while the chlorosis in frenching appears at the tip of the leaf and moves toward the base. The thallium chlorosis also developed to a less extent in the phosphorus-deficient plants than in those in the cultures containing phosphorus, whereas the reverse would be expected for frenching.

Root deterioration was considerably greater in the phosphorus-deficient cultures than in the full nutrient. In these phosphorus-deficient cultures this deterioration was greater in the pH 4.5 series than in the 6.2 series, and greater at the higher thallium concentration than at the lower concentration. In the cultures containing phosphorus, thallium treatments produced smaller roots but no deterioration. Some previous observations of root systems of frenched tobacco plants did not indicate any direct effect of the disease on the roots.

Turkish tobacco was grown in a third water culture experiment to test the effect of renewal compared with non-renewal of the culture solution on the development of thallium chlorosis. The same nutrient salts were used as in the second experiment but each in one-half the concentration. This solution is one in which nutrient deficiencies, particularly nitrogen, develop rather quickly unless it is renewed. It was thought that, in the unrenewed solution, a thallium concentration too low to produce chlorosis in the beginning might in time, coupled with nutrient deficiency, produce a chlorosis and perhaps one similar to frenching. The renewed cultures were held at pH 6.2. The pH of the unrenewed cultures was not controlled. Concentrations of 0.04, 0.06, and 0.08 p.p.m. of thallium in duplicate treatments were used.

Plants about 1 inch high were placed in the cultures on May 25. With concentrations of 0.08 and 0.06 p.p.m. thallium chlorosis appeared within 2 and 5 days, respectively, in both the renewed and

unrenewed cultures. The plants grew out of this in the unrenewed cultures in 10 days but remained chlorotic in the other cultures throughout the experiment. With the 0.04 p.p.m. thallium concentration, chlorosis developed in the renewed solutions in 7 days, but no chlorosis developed in the unrenewed solutions. At no time was the chlorosis in any of the plants severe or similar to frenching.

SAND CULTURE STUDIES

In connection with the earlier studies, Turkish tobacco was grown in acid-treated and washed white silica sand in ½-gallon jars containing varying amounts of Iceland spar. The Iceland spar (through a 40-mesh sieve) was used instead of ordinary pulverized limestone to obtain a purer material and instead of precipitated calcium carbonate to have a material mechanically more like ordinary pulverized limestone. No plants frenched in this experiment. In other experiments with pure sand and chemicals and high-grade limestone, some frenching did occur, but the certainty of getting frenching was very much less than when similar experiments were made with river sand (2).

These jars, after the plants had been removed, were used in an experiment with thallium. Sufficient nutrient salts were added to make possible fair growth but not sufficient to prevent the development of nutrient deficiencies. The Iceland spar treatments per jar (in triplicate) in grams were none, 2, 5, 12, and 24. Two Turkish tobacco plants were set in each jar. One jar in each of the triplicate Iceland spar treatments received thallium. This was added at the rate of 0.01 p.p.m. and was repeated over a period of 2 months to give a total of 0.06 p.p.m. During this time the plants in certain jars were allowed to become nitrogen-deficient to see if this would induce the thallium chlorosis as it does frenching when other conditions are favorable. No chlorosis developed, however, either with or without thallium. The Turkish plants were removed, nitrogen, phosphorus, and potassium additions were made, and two Burley tobacco seedlings were set in each jar on April 19, 1937. On May 1, thallium was added at the rate of 0.036 p.p.m. not only to the jars receiving thallium as stated above, but also to one additional jar in each Iceland spar treatment. A severe yellow chlorosis developed in the smaller leaves of the growing points within 8 days in all the thallium-treated jars except two of those which received the thallium beginning May 1. This disappeared within 7 days. Further applications of thallium were then made over a 5-week period to give a total of 0.195 p.p.m. beginning with the May 1 addition, but no further chlorosis developed. The plants were cut back and suckers allowed to grow. Beginning when the suckers were 1 inch long, thallium was added at the rate of 0.05 p.p.m. at weekly intervals to all jars previously thallium treated to give a total of 0.20 p.p.m. of thallium per jar during the growth of the suckers. No chlorosis developed in the suckers.

A second experiment was set up with a fresh lot of pure sand, nutrient salts, and pulverized Iceland spar (through a 40-mesh sieve) to study the effect of thallium in producing chlorosis in Turkish tobacco. The nutrients added per jar were 1.00 gram $Ca(NO_3)_2$.

$4H_2O$, 0.25 gram K_2HPO_4, 0.2 gram $MgSO_4$, 0.004 gram $MnCl_2 \cdot 4H_2O$, 0.001 gram H_3BO_3, and 3 cc of a saturated solution of ferric tartrate. Additional iron was added as needed. Two plants were set per jar. Details as to the Iceland spar and thallium additions and the chlorosis produced are shown in Table 1. Again, considered in all aspects, the chlorosis did not resemble frenching.

TABLE 1.—*Chlorosis in Turkish tobacco grown in sand with varying amounts of thallium and Iceland spar.**

Jar No.	Iceland spar, gms.	Rate of thallium addition, p.p.m.	Degree of chlorosis			
			June 27	July 6	July 24	August 9
1	0	0	None	None	None	None
2	0	0	None	None	None	None
3	0	0.02	None	Mild	None	None
4	1	0.02	None	Mild	None	None
5	3	0.02	None	None	None	None
6	6	0.02	None	None	None	None
7	0	0.04	None	Medium	None	None
8	1	0.04	None	Medium	Mild	None
9	3	0.04	Mild	Medium	Medium	Mild
10	6	0.04	Mild	Medium	Mild	None
11	0	0.06	Mild	Medium	Medium	Mild
12	1	0.06	Mild	Medium	Medium	None
13	3	0.06	Mild	Medium	Medium	None
14	6	0.06	None	Mild	Mild	None
15	0	0.08	None	Medium	Mild	Mild
16	1	0.08	Mild	Severe	Severe	Severe
17	3	0.08	Mild	Severe	Severe	Severe
18	6	0.08	Mild	Mild	Mild	Severe

*The plants were set April 28, 1937. Thallium nitrate was added eight times beginning May 19. No chlorosis developed up to June 15, when the plants were cut back and suckers allowed to grow.

SOIL CULTURE STUDIES

The effect of thallium in producing chlorosis in tobacco and its relation to frenching also was studied in soil cultures. In addition treatments were included of zinc sulfate, manganese sulfate, aluminum chloride, copper sulfate, and boric acid. The soils were from (a) an area on the Experiment Station farm at Lexington, and (b) a plot receiving manure and limestone at the Mayfield soil experiment field. Tobacco has always frenched in the latter soil in the greenhouse and usually, but not always, in the former. The respective pH of these soils were 5.95 and 6.75. The treatments in triplicate with each soil were (a) none, (b) thallium, (c) zinc, and (d) a combination of manganese, zinc, boron, aluminum, and copper. The thallium additions were repeated every few days, the rate increasing during the experiment as follows: December 14 to January 29, 0.325 p.p.m.; January 30 to February 12, 0.650 p.p.m.; February 13 to 28, 1.625 p.p.m., and March 1 to 14, 3.25 p.p.m. The total added was about 38 p.p.m. or 0.0608 gram thallium per jar. The zinc, manganese, aluminum, boron, and copper treatments and the first thallium treatment were added in solution and mixed with the soil before it was placed in the jars. Two Turkish tobacco plants per jar were set on December 14. One-half gallon glazed earthenware jars were used.

No frenching or thallium chlorosis had developed in the plants in any of the treatments on the Experiment Station farm soil up to March 7, though 28 p.p.m. of thallium had been added to the thallium-treated jars.

No data on the amount of thallium in soils has come to our attention but Clark and Washington (1) have estimated that the amount in the 10-mile crust (hydrosphere and lithosphere) is less than 1 part of thallium per billion. Seemingly the amount added in the soil culture experiments is much greater than that ever present in soils. The plants were nitrogen deficient and budding out at this time. They averaged 30 inches in height and the plants in the thallium-treated jars had made fully as much growth as the others.

The plants were cut back and suckers allowed to grow, growth being good except in the thallium-treated jars. These plants made only about one-third as much growth as the others, and the leaves during early growth were entirely yellow, distorted, and strapped, but not frenched. Three of these plants died, while one developed a normal growing point but a marginal spotting appeared in the older leaves, apparently due to thallium. The other thallium-treated plants remained severely chlorotic, but with no indication of frenching. The plants in the other treatments were 12 inches high at the close of the experiment. They had both nitrogen and potash deficiency symptoms but there were no indications of frenching.

The plants in the Mayfield soil showed symptoms of phosphorus deficiency by January 8. Phosphate additions (0.4 gram $CaH_4(PO_4)_2 \cdot H_2O$) were made to one jar in each treatment on February 5 and again on March 7. Nitrogen deficiency developed later. The plants in all jars frenched, but those in the jars receiving phosphate frenched later and less severely than the others. Thallium toxicity did not develop in any of the plants, and on the whole the plants in the thallium-treated jars frenched later than the others and no more severely. The plants were removed on April 8 after having made fair-sized growth. None of the treatments affected growth materially. The soils were removed from each jar and after nitrogen, phosphorus, and potassium additions had been made, were returned to the jar. Two Turkish tobacco plants then were set in each jar. Except in the thallium-treated jars, they made good growth, and by July 14 were, on the average, 36 inches high. Some nitrogen deficiency had developed; however, none of the plants frenched. The plants in the jars which had received a total of 38 p.p.m. of thallium during the growth of the previous crop were entirely yellow within a few days after setting and never recovered from this chlorosis or made any growth though they lived during the entire experiment. (See Fig. 2.)

A second soil culture experiment was made with the Mayfield soil. One Turkish tobacco plant and one hybrid Burley plant (for a purpose not related to this paper) were set in each jar. Thallium was added from February 25 to May 8 to two of the jars, on alternate days, at the rate of 0.065 p.p.m. Chlorosis developed in the Turkish plant in one of the thallium-treated jars on March 18 at which time 7.150 p.p.m. of thallium had been added. It disappeared on April 5 even though thallium additions had continued to bring the total at this

time to 11.05 p.p.m. The thallium-treated plants were stunted, being only about one-third the size of the other plants. All the plants frenched but those in the thallium-treated jars later and less severely than the others. Phosphorus and nitrogen deficiency developed during the experiment.

In the latter part of the experiment, in an attempt to recover the plants from frenching, nitrogen additions were made at three different times. In two of the jars, one thallium-treated and one not, sodium nitrate was used, and in the other two jars calcium nitrate. The original growing points in none of the plants recovered from their frenched, rosetted condition. The calcium nitrate-treated plants, however, threw out numerous suckers which made little growth and remained very severely frenched, while the sodium nitrate-treated plants produced two suckers each which, though frenched at first, recovered, made good growth, and never frenched again. This difference in effect of the two nitrogen salts on frenching is mentioned in a previous publication (2).

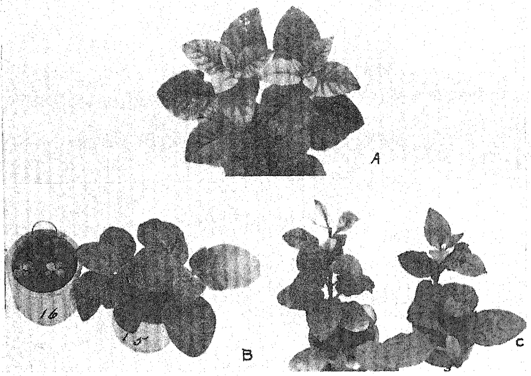

FIG. 2.—Plants grown in soil cultures. A, Turkish tobacco showing moderately severe frenching and severe phosphorus deficiency spotting. Plants grown in Mayfield soil, plot 202, ML, pH 6.75, jar 24 treated with Mn, Zn, B, Cu, and Al. B, Turkish tobacco plants showing the effect of thallium on the second crop of plants in the Mayfield soil. Jar 15 received no thallium. Jar 16 received 38.025 p.p.m. of thallium during the growth of the first crop, with no visible effect on the plants. C, Turkish tobacco grown in the Mayfield soil which had been field treated with manure and limestone (pH 6.75). Plant 2 untreated; plant 3 thallium treated; 13.975 p.p.m. of thallium had been added at the time of frenching. The yellow-vein type of chlorosis appears on a leaf about the center of plant 3. The plants frenched the same day. The plant at the front of each jar is a Burley hybrid.

SUMMARY

Studies at the Kentucky Agricultural Experiment Station have shown that frenching of tobacco is related to the reaction or lime content of the soil and to the soil nutrient supply. More recently, studies have been made with particular reference to the effect of thallium on growth of tobacco plants in water, sand, and soil cultures. Thallium addition caused chlorosis in all three cultures. Additions of 0.04 p.p.m. of thallium produced chlorosis in Turkish tobacco seedlings in water cultures. Larger amounts were required in most sand cultures though 0.035 p.p.m. produced chlorosis in one set. This disappeared, however, even though the thallium additions were continued to give a total of 0.395 p.p.m. Much larger amounts were required in the soil cultures, 7.15 p.p.m. producing temporary chlorosis in one soil culture experiment. In another experiment a total of 28 p.p.m. did not produce chlorosis.

This thallium-induced chlorosis appeared in several forms, but all of these were unlike frenching in several respects. Frenching of the type appearing in the field starts in the interveinal tissue of the apical margin, while the thallium-induced chlorosis appears in the tissue at the base of the leaf and along the larger veins. Thallium-induced chlorosis also may appear first in the larger leaves of the plant, while the first symptom of frenching appears only in the top leaves of the main plant or the suckers.

Thallium treatments did not hasten frenching in soils in which frenching occurs in the field, nor did thallium treatments produce frenching in soils in which frenching does not occur in the field. Liming and a low nutrient content did not increase thallium chlorosis, whereas these conditions do tend to produce frenching.

A much greater amount of thallium was required to cause chlorosis in the soil cultures than presumably is ever present in soils where frenching occurs.

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MICROBIAL ACTIVITY IN RELATION TO SOIL AGGREGATION[1]

T. C. PEELE[2]

THE physical conditions of soils influence their productivity and resistance to erosion. The degree of aggregation of the clay into large water-stable granules has been widely used as an index of the physical properties. Soils in which a high proportion of the silt and clay is in the form of water-stable granules are comparatively permeable to air and water, are relatively resistant to erosion, and provide good media for plant growth. Any procedure which tends to promote aggregation of the finer soil separates may be expected to improve the soil structure and to result in a decrease in erosion. A number of workers have shown that additions of organic matter to soil result in improved physical conditions. Some of the effects on the physical properties attributed to the incorporation of organic matter with soil are increase in aggregation of the silt and clay, increase in infiltration rate, decrease in field volume weight, increase in moisture retention, and decrease in runoff and erosion.

The increase in infiltration rates and the decrease in runoff and erosion are probably due largely to the effect of the organic matter on soil aggregation and to the mulch effect of the portion of the organic matter which remains on the surface of the soil. The mechanism of soil aggregation in all its phases has never been clearly explained. However, from the considerable amount of data available on this subject it appears certain that there are several kinds of binding agents involved in the formation of different types of soil aggregates. These binding agents may be roughly divided into two kinds, inorganic and organic. The aggregation of the B horizon of lateritic soils, such as the Cecil series, furnishes an excellent example of aggregation due to inorganic binding forces. Frequently these soils will contain 50% or more clay and over 95% of the particles may be aggregated into water-stable granules larger than 0.02 mm. The organic matter content is usually less than 1% in the B horizon, and it does not seem likely that this small amount could cause the aggregation observed in these soils.

The organic binding forces may be divided for convenience into two groups. The first group is made up of colloids consisting of the decomposition products of plant residues probably of the lyophobic type and similar to the ones described by Myers (2)[3], most of which are included in dilute alkali extracts of well-decomposed organic matter. The other group consists of the cells of micro-organisms and their secretory products, such as mucus, slime, or gum, produced during growth and resembling lyophilic colloids and gels in their physical state. These growth products of micro-organisms have re-

[1]Contribution of the Soil Conservation Service in cooperation with the South Carolina Agricultural Experiment Station, Clemson, S. C. Received for publication December 11, 1939.

[2]Soil Technologist.

[3]Figures in parenthesis refer to "Literature Cited", p. 212.

ceived scant attention as a factor in the formation of soil structure, particularly as a binding agent in the development of water-stable soil aggregates.

The work of Shrikhande (4, 5) showed that there was a large increase in stickyness of straw during its decomposition. Kanivetz and Korneeva (1) reported an increase in percentage of water-stable aggregates in soils infected with Azotobacter and Trichoderma. They found that organic matter in the form of straw when infected with *Trichoderma lignorum* and added to the soil caused a sixfold increase in proportion of water-resisting aggregates.

Waksman and Martin (7) presented data showing a marked increase in percentage of bound material when sand-bentonite mixtures containing sucrose or cellulose were inoculated with pure cultures of bacteria and fungi. They reported that similar results were obtained using sand-clay mixtures. The binding action of the fungi was attributed to the extensive mycelium and the binding action of *Azotobacter indicum* to the slimy substances produced by the organism.

It is the purpose of this paper to present the results of some preliminary studies dealing with the relation of microbial activity to soil structure and showing conclusively that water-stable aggregates can be formed from the mucus produced by bacteria.

MATERIALS AND METHODS

The media used in this investigation are listed below:

Medium 1

Agar	15.0 grams
Peptone	1.0 grams
Dextrose	2.5 grams
KH_2PO_4	0.25 gram
$FeCl_3$	trace
$MgSO_4 \cdot 7H_2O$	trace
Distilled water	1 liter

Reaction adjusted to pH 6.3 using NaOH

Medium 2

Agar	15.0 grams
Dextrose	1.0 grams
Peptone	0.15 gram
Asparagine	0.15 gram
$MgSO_4 \cdot 7H_2O$	0.10 gram
$CaCO_3$	0.10 gram
KH_2PO_4	0.10 gram
$FeCl_3$	trace
Distilled water	1 liter

Reaction adjusted to pH 6.6 using NaOH

Medium 3

Peptone-glucose acid agar (6)

Agar	25.0 grams
KH_2PO_4	1.0 grams
$MgSO_4 \cdot 7H_2O$	0.5 gram
Peptone	5.0 grams
Glucose	10.0 grams
Water	1 liter

Reaction adjusted to pH 3.8 to 4.0 using sulfuric acid

The procedure used in making aggregate analyses was similar to that previously reported (3) with the exception that a wet-sieving operation has been included in order to obtain a measure of the coarser aggregates. The results obtained from aggregate analysis are influenced considerably by the procedure used in making the determinations, and until some uniform procedure is adopted by different laboratories for making these analyses, it is highly desirable that the exact procedure used be given by each investigator in reporting the results of his work.

In the present investigation the soil was allowed to become air-dry and a moisture determination made the day preceding analysis. Soil aggregates or lumps larger than 2 mm in diameter were used in the analysis. Fifty grams (oven-dry basis) of the air-dry soil were placed in a 600-ml beaker and wetted with 400 ml of distilled water. The soil was allowed to slake for 3 hours and transferred by means of a wash bottle to a 2-mm sieve 5 inches in diameter resting in a small container with the bottom of the sieve covered by about ½ inch of distilled water. The sieve was moved gently up and down in the water until all soil particles less than 2 mm in diameter had passed through it. The soil on the sieve was transferred to a tared beaker, oven-dried, and weighed. The soil suspension containing particles less than 2 mm in diameter was transferred to a 1-liter graduated cylinder and the volume made up to 1 liter using distilled water. The cylinder was shaken end over end and the temperature recorded. It was then shaken end over end five times, placed upright on a level surface, and hydrometer readings, using a Bouyoucos hydrometer, were made at appropriate intervals to obtain the amount of soil in suspension having diameters of 0.05 and 0.02 mm or less. The settling times at which the readings were made are taken from Table 1. The values in this table were calculated by the procedure previously outlined (3). The hydrometer readings must be corrected by adding 0.2 gram for each degree Fahrenheit above 67 or subtracting this amount for each degree the temperature of the soil suspension is below this figure when the hydrometer readings are made.

TABLE 1.—*Aggregate analysis by the hydrometer method.*

Particle size, mm.	Sedimentation time for hydrometer readings	
	Temperature 17.5° to 22.5° C	Temperature 22.5° to 27.5° C
0.05	45 sec.	38 sec.
0.04	1 min., 10 sec.	1 min., 0 sec.
0.03	2 min., 0 sec.	1 min., 50 sec.
0.02	4 min., 35 sec.	4 min., 0 sec.
0.01	18 min., 15 sec.	16 min., 10 sec.

In calculating the percentage of soil in aggregates of the different sizes the fraction above 2.0 mm in size is obtained from the oven-dry weight of soil retained by the sieve. The fraction 0.05 to 0.02 mm in diameter and the one less than 0.02 mm in diameter are obtained from the corrected hydrometer readings. The corrected reading for particles 0.02 mm in size is subtracted from the corrected reading for particles 0.05 mm in size in order to obtain the fraction having diameters of 0.05 to 0.02 mm. The soil fraction having diameters of 2.0 to 0.05 mm is obtained by the difference between the weight of the other fractions and the oven-dry weight of the original sample. All aggregate analyses reported are averages of duplicate determinations.

EXPERIMENTAL RESULTS

A number of cultures of rod-shaped bacteria were isolated from Cecil clay loam. One of these cultures (No. 21) was used in testing the effect of bacterial mucus on soil aggregation. The organism is a large, aerobic, spore-forming rod and produces viscous mucus on solid media. The bacteria were grown on slopes of medium 1 for a period of about 3 days, which was sufficient for the production of abundant growth on the surface of the agar, the growth consisting of the living cells of the bacteria plus the mucus or slime produced during growth. Portions of the mucus were removed from the surface of the medium and incorporated with air-dry soil (Cecil clay) which had previously been passed through a 1-mm sieve. The soil and mucus were kneaded together and shaped in the form of small, round granules about ¼ inch in diameter. The granules were then allowed to become air-dry. Similar granules were made using the same soil and using distilled water instead of the bacterial mucus.

The air-dry granules made with mucus and those made with water were placed in distilled water and allowed to slake. The granules made with bacterial mucus were very stable and did not disintegrate even after continuous soaking for 24 hours. The granules made with distilled water disintegrated completely in one minute or less. Fig. 1 shows a Cecil clay granule bound by slime of culture 21 grown on medium 1. The air-dry granule was placed in distilled water and had been soaking for 40 minutes when the photograph was made with the granule still immersed in water. Fig. 2 shows the same granule after soaking for 24 hours. There was no visible slaking after soaking for 24 hours. It is evident that the granules bound with the mucus of bacteria were water-stable. This binding action is not a specific property of the bacterial specie reported but appears to be a general property of all bacteria which produce considerable quantities of mucus. A number of different species have been tested and in every case it was possible to produce water-stable aggregates from their mucus, although the degree of stability of the aggregates varied widely with different species and appeared to be associated with the viscosity of the mucus.

The binding action of the mucus seems to be due largely to the cohesiveness of the mucus for soil and to the fact that the colloidal mucus reacts irreversibly on dehydration as a result of becoming air-dry or, if not entirely irreversible, the hydration after air-drying

proceeds extremely slowly. The binding action of the mucus is not only effective with the inorganic colloidal soil material but also binds the coarser separates, such as sand.

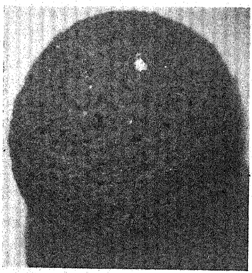

FIG. 1.—Granule of Cecil clay bound by mucus of bacterial culture No. 21, photographed in water after soaking for 40 minutes. Actual diameter of granule was ¼ inch.

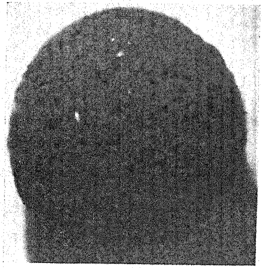

FIG. 2.—Granule of Cecil clay bound by mucus of bacterial culture No. 21 photographed after soaking in distilled water for 24 hours. Note lack of slaking.

The mucus from an agar culture of Austrian field pea nodule bacteria was mixed with white quartz sand having diameters of approximately 0.20 mm. The sand and mucus were kneaded together and shaped into a small granule. A similar granule was made using only distilled water. Both granules were allowed to become air-dry. The granule made with mucus retained its shape, but the one made with distilled water only disintegrated completely on drying as would naturally be expected since there was no binding agent present. The granule containing mucus was placed in distilled water and allowed to soak for 30 minutes. There was no evidence whatever of disintegration as a result of this soaking. Fig. 3 shows the quartz bound with mucus after soaking for 30 minutes, and Fig. 4 shows quartz grains of the size used in making the granule, the magnification being the same in each case.

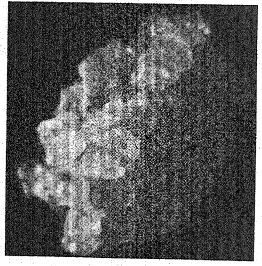

FIG. 3.—White quartz granule bound with mucus of Austrian field pea nodule bacteria. Photographed after the air-dry granule had soaked for 30 minutes in distilled water. Note lack of disintegration. Actual diameter of granule approximately ¼ inch.

The evidence shows that water-stable granules can be easily pro-

duced under artificial conditions by incorporating bacterial mucus with soil. In order to determine the effect on aggregation of micro-organisms growing directly in the soil, an experiment was conducted in which the activity of the soil micro-organisms was markedly increased by the addition of a readily available source of energy to unsterile soil. A sugar (sucrose) was selected as the energy source chiefly for two reasons. First, it was known that the sucrose would cause a large increase in growth of soil bacteria and fungi, and second it would, to a large extent, be broken down completely to carbon dioxide and water and would not leave appreciable quantities of

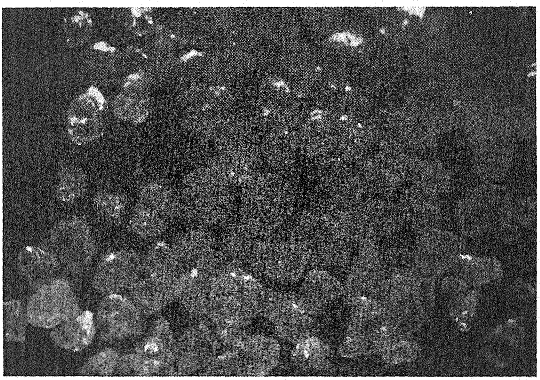

FIG. 4.—White quartz grains of the size used in making the granule shown in Fig. 3. Actual diameter of quartz grains approximately 0.2 mm.

organic residues, other than secretory products and cellular material of micro-organisms, which might serve as binding agents and complicate the interpretation of the results.

The A horizon of a lateritic soil (Cecil sandy loam) was collected from the South Carolina Agricultural Experiment Station farm. The soil was air-dried, passed through a 1-mm sieve, and thoroughly mixed. Aliquot portions of 800 grams each were placed in small, glazed containers. The treatments received by different containers, together with the results obtained, are shown in Table 2. Sucrose applications were at the rate of 16 tons per acre based on 2,000,000 pounds oven-dry soil per acre. On the same basis, nitrogen, phosphorus, and potassium applications were made at the rate of 500 pounds each and calcium carbonate at 2 tons per acre. The sucrose and calcium carbonate were incorporated with the soil dry and the other treatments were added in solution. The moisture content of the soil was raised to 5% above the moisture-equivalent at the beginning

TABLE 2.—*Effect of microbial activity on soil aggregation.*

Treatments*	Incubation time	Bacteria in soil at end of incubation, millions per gram	Fungi in soil at end of incubation, millions per gram	Percentage of different size aggregates			
				Above 2.0 mm.	2.0–0.05 mm.	0.05–0.02 mm.	Below 0.02 mm.
Sucrose	None†	‡	‡	0	65.7	11.0	23.3
N-P-K	1 day	‡	‡	0	72.2	12.5	15.3
Sucrose+N-P-K	1 day	‡	‡	62.0	26.5	4.9	6.6
Sucrose+N-P-K+ $CaCO_3$	1 day	‡	‡	23.5	56.0	9.5	11.0
None	18 days	9.83	0.04	0	76.6	10.8	12.6
N-P-K	18 days	9.97	0.04	0	74.2	12.0	13.8
Sucrose+N-P-K	18 days	465.00	5.37	57.7	33.7	4.0	4.6
Sucrose+N-P-K+ $CaCO_3$	18 days	367.00	0.82	54.5	37.6	3.5	4.4

*N, P, K (nitrogen, phosphorus, and potassium) applied at rate of 0.025 gram each per 100 grams soil. Sucrose applied at rate of 1.6 grams and $CaCO_3$ 0.2 gram per 100 grams soil on oven-dry basis.

†Soil wetted and dried immediately.

‡No bacteria or fungi counts were made on the soils incubated less than 18 days.

and at intervals of 3 or 4 days during the incubation period. Some of the cultures were incubated for 18 days and some for 1 day. In one case sucrose-treated soil was wetted and allowed to air-dry immediately in order to determine whether the sucrose had any effect on aggregation when no incubation time was allowed for the micro-organisms to develop. Numbers of bacteria and fungi present in the soil were determined by the plate method at the end of the 18-day incubation period and were determined only in soil cultures which were incubated for this length of time. The bacterial counts were made using medium 2 and the fungi counts using medium 3. Aggregate analysis was made on all soils immediately after the end of the incubation periods and was preceded by air-drying in each case.

The results in Table 2 show that the addition of sucrose caused a marked increase in the percentage of water-stable aggregates larger than 2 mm. This effect on aggregation occurred only when an incubation period permitting the development of the micro-organisms ensued after the sucrose was added to the soil. When the sucrose was added and the soil dried immediately, thus preventing the growth of the micro-organisms, there was no increase in aggregation of the soil. Mineral nutrients appeared to have little effect on the numbers of bacteria and fungi present in the soil, with the exception of calcium carbonate which depressed the growth of the fungi and to some extent the numbers of bacteria present. Nitrogen, phosphorus, and potassium did not have any appreciable effect on aggregation. The sucrose plus calcium carbonate treated soil was somewhat less strongly aggregated at the end of 1 day's incubation than the soil receiving sucrose without calcium carbonate. The soil treated with sucrose plus

nitrogen, phosphorus, and potassium but without calcium carbonate, when incubated for 1 day only, contained a slightly higher percentage of aggregates above 2.0 mm in diameter than did a similarly treated soil incubated for 18 days. However, it is doubtful whether this slight difference is significant, and it may be noted that the sucrose-treated soil incubated for 18 days had a higher percentage of aggregates larger than 0.05 mm in diameter than did the soil incubated only 1 day.

After finding that water-stable soil aggregates could be produced by stimulating the growth of the natural soil population through the addition of sugar, it was thought desirable to study this process under aseptic conditions using pure cultures of bacteria and fungi. Portions of the original soil sample collected for the preceding experiment, which had been air-dried and passed through a 1-mm sieve, were placed in 1-liter flasks, plugged with cotton, and sterilized in an autoclave at 15 pounds pressure for 3 hours. Sucrose solution and distilled water containing 0.05% $NaNO_3$ and 0.05% KH_2PO_4 were sterilized separately at 15 pounds pressure for 20 minutes. The sucrose solution and sterile water containing the mineral nutrients were added to the flasks in the desired amounts after the sterile soil had cooled. Inoculations of fungi and bacteria were made by means of water suspensions of the organisms. The flasks were all incubated for 12 days, then the soil was removed, rapidly air-dried, and its degree of aggregation determined. The treatments and results obtained are shown in Table 3.

TABLE 3.—*Effect of microbial activity on soil aggregation.**

Treatments	Percentage of different size aggregates			
	Larger than 2 mm.	2 to 0.05 mm.	0.05 to 0.02 mm.	Less than 0.02 mm.
Sterile soil, no treatment	0	71.0	12.5	16.5
Sterile soil plus sucrose	0	72.5	9.5	18.0
Sterile soil plus sucrose inoculated with *C. blakesleeana*	79.0	11.3	2.5	7.2
Sterile soil plus sucrose inoculated with bacterial culture 7	6.5	72.2	10.8	10.5
Sterile soil plus sucrose plus fresh soil suspension	14.4	68.4	8.5	8.7

*Date reported are averages of duplicate treatments.

The data in Table 3 show that a marked increase in aggregation occurred when sterile soil containing sucrose was inoculated with cultures of bacteria or fungi and incubated for a sufficient time to permit good development of micro-organisms. When sterile soil containing sucrose was incubated, the sugar had no effect on aggregation. The fungous culture was much more effective than the bacterial culture or the mixed culture represented by the fresh soil suspension inoculation in promoting the formation of water-stable aggregates. This indicates a possibility that it may be plausible to inoculate with a suitable fungous culture areas where green manure is being incorporated

with soil and where it is desired to increase the degree of aggregation. However, a decision on that point must await further investigation. Preliminary tests have indicated that there is a large variation in the effect of different species of bacteria on soil aggregation, and it is probable that some bacteria are more effective than some species of fungi in causing the formation of water-stable granules.

SUMMARY

The mucus produced by bacteria was found to be an effective binding agent in the formation of water-stable soil granules. Bacterial mucus from Austrian field pea nodule bacteria and various other bacterial species grown on artificial media produced water-stable aggregates when incorporated with soil. This was true whether the soil contained a large amount of clay or consisted entirely of quartz sand.

The addition of sucrose to soil containing bacteria or fungi and followed by an incubation period caused a marked increase in percentage of large water-stable granules. When sucrose was incorporated with soil under sterile conditions and the soil maintained free of micro-organisms, it had no effect on aggregation.

A fungous culture was much more effective than a bacterial culture in producing water-stable granules under aseptic conditions, but it is probable that this relationship varies with different species of both kinds of organisms.

The activities of micro-organisms appear to be of much greater importance in connection with soil structure than their consideration in the past would indicate.

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EFFECT OF POLLINATION UPON CHEMICAL COMPOSITION OF SILKS OF CERTAIN INBRED LINES OF MAIZE[1]

Irwin R. Hoener and Ralph O. Snelling[2]

IN a study of the chemical composition of developing ears of maize and of the influence of composition upon the resistance of certain strains to the corn earworm (*Heliothis obsoleta*, Fab.), data have been obtained relative to the effect of pollination on the composition of the silks.[3]

The pollination of maize silks has an immediate retarding effect upon their development, while unpollinated silks will continue to increase in length and total volume. If pollination were prevented, therefore, it would result in a much larger volume of silks for analysis. While prevention of pollination would facilitate the technic in providing sufficiently large samples, it was not known whether the composition of silks grown under such conditions would be comparable with that of silks on which the corn earworms normally feed. The data reported here indicate the effect of pollination on protein and moisture content of the silks, and on the H-ion concentration and the refractive index of the juice expressed from them.

MATERIALS AND METHODS

Inbred lines Kansas K4, Iowa L317, Ohio 51, and U. S. 540, grown at Urbana, Illinois, in 1938 were used in this study. Silks from four rows of each inbred were analyzed. In two alternate rows pollination was prevented by covering the young shoots with parchment bags before the silks had emerged. The remaining two rows of each inbred were left without bags to be normally pollinated. Approximately 100 plants were represented in each of the samples.

SAMPLING AND PREPARATION FOR ANALYSES

The silks of inbred 51 were sampled July 30; 540 and K4 on August 5, and L317 on August 12, 1938. These samples were taken approximately 72 hours after emergence, which was before any outward appearance of drying was evident. The shoot bags were removed from the unpollinated silks about four o'clock in the afternoon the day before the samples were taken. This should have enabled any moisture differences, due to the bags, to become adjusted, and it is believed that very few silks were pollinated during this period of exposure, although it is realized that some pollen often is shed late in the afternoon. The samples were taken the next morning before significant amounts of pollen had been released.

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill., and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Received for publication December 26, 1939.

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[3]The writers wish to express their sincere appreciation to Dr. E. E. DeTurk for his advice and to Mr. C. H. Shannon for his help in making some of the analyses. The cooperation of Mr. R. A. Blanchard is acknowledged in connection with the project on the causes of corn earworm resistance.

The silks were removed from the shoots by cutting just at the tip of the developing husks. They were immediately cut fine and mixed in a Hobart salad cutter. The juice for H-ion concentration and refractive index determinations was expressed at once from a portion of the cut sample at approximately 2,000 pounds pressure to the square inch. The juice was relatively free of solid material and was not centrifuged before making these analyses. A portion of the mixed sample was dried for the moisture and the protein determinations.[4]

ANALYTICAL METHODS

Moisture.—Moisture was determined by drying a portion of the original sample at 85° C in an electric vacuum oven under a pressure of 100 mm mercury.

Total nitrogen.—Total nitrogen was determined on a portion of the dried silks by the official Kjeldahl-Gunning-Arnold method.

H-ion concentration.—H-ion concentration was determined by the Beckman pH meter and expressed as pH values.

Refractive index.—The refractive index was determined by use of an Abbé refractometer.

DISCUSSION OF RESULTS

Moisture.—In each of the four inbred lines the percentage of moisture was less in the pollinated than in the unpollinated silks. Removal of the shoot bags approximately 17 hours previous to sampling should have permitted the silks to become adjusted from any influence of the bags. The most plausible explanation for this difference is that incipient drying of the silks occurred very soon after pollination even though outwardly the pollinated silks appeared to be as fresh and succulent as those unpollinated. The moisture content of the L317 silks was higher than that of the other inbreds. This may be partially due to conditions at the time of sampling. The sample of L317 silks was taken later than the other samples because of the slightly later silking date of this inbred.

Protein.—The silks from the four inbred lines of corn differed only slightly in the percentage of protein with the exception of L317 which was about 50% higher than the other three. In each inbred, however, the percentage of protein was higher in the pollinated than in the unpollinated silks. As shown in Table 1, the protein content of pollinated silks from inbreds L317 and 540 had more than 1% more protein than the unpollinated silks. The difference in protein in favor of pollinated silks was only 0.44% in inbred 51. No explanation is offered for the considerably higher protein content in silks from L317 except that it is possibly a genetic difference. It is not believed that the difference in time of silking is responsible for its higher protein content as was suggested in regard to its high moisture.

H-ion concentration.—The pH values of the expressed juice of both the pollinated and the unpollinated silks of L317 were slightly higher than those of the other strains. In inbreds K4 and L317 there was no significant change in the H-ion concentration of the juice because of pollination, while in inbred 51 there was an increase of 0.12 pH in the

[4]The term "protein" refers to the total nitrogen multiplied by the conventional factor 6.25.

TABLE 1.—*Protein and moisture content of pollinated and unpollinated silks and H-ion concentration and refractive index of the juice expressed from them for inbred lines Kansas K4, Iowa L317, Ohio 51, and U. S. 540, Urbana, Illinois, 1938.*

Condition of silks	Inbred K4	Inbred L317	Inbred 51	Inbred 540
	Percentage Protein*			
Unpollinated	13.97	20.97	14.72	14.13
Pollinated	15.00	22.07	15.16	15.22
Difference	+ 1.03	+ 1.10	+ 0.44	+ 1.09
	Percentage Moisture			
Unpollinated	89.29	91.82	88.68	89.86
Pollinated	89.06	91.33	87.10	89.02
Difference	− 0.23	− 0.49	− 1.58	− 0.84
	H-ion Concentration of the Juice			
Unpollinated	5.13	5.43	5.12	5.18
Pollinated	5.10	5.41	5.24	4.75
Difference	− 0.03	− 0.02	+ 0.12	− 0.43
	Refractive Index of the Juice, 20° C			
Unpollinated	1.3420	1.3440	1.3450	1.3422
Pollinated	1.3435	1.3440	1.3469	1.3425
Difference	+ 0.0015	0.0	+ 0.0019	+ 0.0003

*Water-free basis.

juice from pollinated silks in contrast to a decrease of 0.43 pH in the juice from pollinated silks of inbred 540.

Refractive index.—The refractive index of the juice from both pollinated and unpollinated silks of inbred 51 was slightly higher than that of the other inbreds. However, the refractive index of the juice was not markedly influenced by pollination.

SUMMARY

Pollinated and unpollinated silks of four inbred lines of maize were studied as to their protein and moisture content, the H-ion concentration, and the refractive index of their expressed juice approximately 72 hours after emergence.

The pollinated silks of the four inbred lines appeared to be significantly higher in protein content and significantly lower in moisture content than the unpollinated silks. The protein content of the silks of the inbred line L317 was considerably higher than that of the other three inbred lines.

The H-ion concentration of the juice expressed from the silks of K4 and L317 was not influenced by pollination; while that of inbred 51 showed an increase of 0.12 pH and that of inbred 540 a decrease of 0.43 pH apparently as a result of pollination.

Pollination did not appear to influence significantly the refractive index of the juice expressed from the silks.

THE INFLUENCE OF GRAZING UPON CERTAIN SOIL AND CLIMATIC CONDITIONS IN FARM WOODLANDS[1]

ROBERT F. CHANDLER, JR.[2]

IT is widely recognized that the grazing of farm woodlands in the eastern United States is an undesirable practice. Observations as well as experimental data show that intense grazing utlimately results in the destruction of all forest-tree reproduction, as well as considerable crown injury and decreased growth rate in the overstory (1, 8, 9, 10).[3]

Many factors have been suggested as being responsible for the general decrease in growth and vigor of the trees. Some of the suggested causes are compaction of the surface soil when trampled by cattle, disintegration and loss of litter due to excessive drying and to having been blown away, and lack of available soil moisture. Adequate experimental data indicating the extent to which grazing has influenced these conditions seem to be lacking in the literature. It is the purpose of this paper to present some actual measurements of certain soil and climatic conditions in 18 grazed and an equal number of ungrazed farm woodland areas in central New York. The factors studied are listed as follows: Hydrogen-ion concentration (pH), organic matter content, volume weight, moisture equivalent, moisture content, degree of aggregation of soil particles, soil temperature, air temperature, light intensity and relative humidity.

MATERIALS AND METHODS

The various woodland areas were so selected that a grazed and ungrazed area could be studied on the same soil type. Many times only a fence separated the two areas, and in no case was the distance between the compared grazed and ungrazed areas more than ½ mile. The climatic data were obtained from both areas within a period of less than 1 hour.

The ungrazed woodlands consisted of fully-stocked second-growth hardwood stands, the dominant trees of which exceeded 60 years of age. The soils were virgin in that they had never been cultivated or pastured. The stands on the grazed areas were of similar species composition and age, except that reproduction and all younger-aged trees were missing. The stage of grazing corresponded to the open park and final stages as defined by Day and DenUyl (8). The original humus layer had disappeared, and a grass cover was essentially the only ground vegetation on the areas. Fig. 1 shows representative grazed and ungrazed woodlands on the same soil type. Differences of this order occurred between all paired comparisons.

Statements concerning the location, soil type, humus-layer type (12), and principal forest tree species present on the various grazed and ungrazed areas are presented in Table 1. In order to conserve space, the experimental area numbers are also presented, and are used for identification purposes in subsequent tables.

[1]Contribution from Department of Agronomy, Cornell University, Ithaca, N. Y. Received for publication December 26, 1939.

[2]Research Assistant Professor of Forest Soils.

[3]Figures in parenthesis refer to "Literature Cited", p. 230.

In order to determine the volume weight soil samples were collected according to the method of Burger (4), being obtained by driving a steel cylinder of 1,000-cc

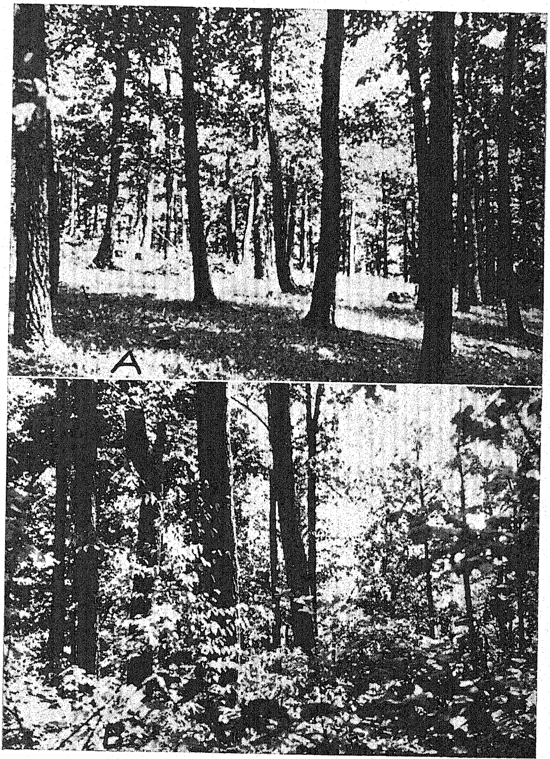

FIG. 1.—Photographs of typical paired woodland areas on Lordstown silt loam soil. A, grazed; B, ungrazed.

volume into the soil. All areas were sampled in duplicate. The samples were carefully transferred to 1 gallon waterproof cardboard containers. After being transported to the laboratory the samples were weighed, dried, and reweighed to obtain

TABLE 1.—*Soil type, humus-layer type, and principal forest tree species on the various experimental plots on the grazed and ungrazed woodlands.*

Experimental area No.	New York state county in which located	Soil type	Humus layer type	Principal forest trees present	
				Grazed	Ungrazed
I	Cayuga	Ontario loam	Coarse mull	Sugar maple, basswood, Americam elm	Sugar maple, basswood, American elm
II	Wayne	Ontario loam	Coarse mull	Sugar maple, basswood	Sugar maple, basswood
III	Wayne	Ontario loam	Coarse mull	Sugar maple	Sugar maple, basswood, white ash
IV	Ontario	Ontario loam	Coarse mull	Sugar maple, red oak, basswood	Sugar maple, red oak, basswood
V	Wayne	Ontario loam	Coarse mull	Sugar maple, shagbark hickory	Basswood, sugar maple, beech
VI	Wayne	Ontario loam	Coarse mull	Sugar maple, basswood, beech	Sugar maple, basswood, beech
VII	Tompkins	Lansing silt loam	Coarse mull	Sugar maple	Sugar maple, basswood, white ash
VIII	Ontario	Dunkirk silt loam	Coarse mull	Sugar maple, beech, basswood	Sugar maple, beech, basswood
IX	Onondaga	Honeoye silt loam	Coarse mull	Beech, sugar maple, basswood	Beech, sugar maple, basswood
X	Onondaga	Honeoye silt loam	Coarse mull	Sugar maple, American elm, basswood	Sugar maple, American elm, basswood
XI	Tompkins	Volusia silt loam	Coarse mull	Red oak, shagbark hickory, sugar maple	Red oak, shagbark hickory, sugar maple
XII	Tompkins	Volusia silt loam	Coarse mull	Shagbark hickory, red maple, red oak	Shagbark hickory, red maple, red oak
XIII	Cortland	Volusia silt loam	Coarse mull	Sugar maple, white ash, black cherry	Sugar maple, white ash, black cherry
XIV	Tompkins	Lordstown stony silt loam	Thin coarse mull	Red oak, white oak, chestnut oak	Red oak, white oak, sugar maple
XV	Cortland	Chenango gravelly silt loam	Fine mull	Sugar maple, beech	Sugar maple, beech
XVI	Cortland	Lordstown stony silt loam	Granular mor	Sugar maple	Beech, sugar maple
XVII	Cortland	Lordstown silt loam	Root mor	Sugar maple	Sugar maple
XVIII	Tompkins	Lordstown stony silt loam	Root mor	Red oak, chestnut oak, red maple	Red oak, red maple

an estimate of the moisture content at time of sampling. The volume weight was calculated from the dry weight of the sample. Because of the nature of the subsequent determinations to be made on the sample, the above drying took place at a temperature of 60° C instead of the customary 105° C.

The samples were next mixed somewhat with the hands, so as to increase the uniformity. Every effort was made to preserve the aggregates. Representative sub-samples were then transferred to 250 ml beakers and aggregate analysis made in a manner similar to that described by Tiulin (18), with the exception that instead of directing a gentle stream of water onto the soil in the sieves, each sieve was dipped in and out of a basin of water 60 times, and the aggregates remaining on a given sieve were considered as water stable. The size distribution of all particles less than 0.02 mm in diameter was determined by the pipette method. The same soil sample which was passed through the sieves was returned to a beaker and treated with sodium carbonate solution, vigorously stirred with an electric mixer for 10 minutes, and again passed through the sieves to determine the size distribution of the ultimate particles.

Other sub-samples were removed, passed through a 20-mesh sieve, and used for the determination of pH, moisture equivalent, and organic matter content.

The pH was determined potentiometrically, using a glass electrode.

The moisture equivalent determination was made in the usual manner by determining the moisture content of the wet samples after they were subjected to a centrifugal force of 1,000 times gravity for 30 minutes.

A small portion of the soil was ground in an agate mortar to pass a 100-mesh sieve. The organic matter content was estimated according to the modification of the Degtjareff method as proposed by Wakley and Black (20) and as used by Browning (3).

A Taylor humidiguide was used for the determination of air temperature and relative humidity. The measurements were made at about 1 foot from the ground surface.

Soil temperatures were taken with a laboratory thermometer at a depth of 1 inch.

An estimate of the relative size distribution of pores was made on certain soils by the method proposed by Bradfield and Jamison (2).

Light intensity was measured with a Weston sunlight meter. A sheet of white typewriting paper was placed on the ground and the photronic cell was held at a distance of 1 foot, directly above the center of the paper. The reflected light was measured at 20 different spots, about 10 feet apart. Measurement of the intensity of reflected full sunlight was made in the open and all results expressed as percentages of these values. On clear days when the intensity of direct sunlight was about 10,000 foot candles, the reflected light intensity was about 2,200 foot candles.

EXPERIMENTAL RESULTS

In Table 2 are presented the data on the hydrogen-ion concentration, organic matter content, volume weight, moisture equivalent, moisture content at time of sampling, and relative wetness. Since the arrangement of the plats was such as to permit paired comparisons, Student's Z method (14) was used to determine statistical significance of the differences between means. For each condition studied, the mean, the difference between means, and the odds against a difference as great as that occurring due to chance alone, are given.

TABLE 2.—*Hydrogen-ion concentration (pH), organic matter content, volume weight, moisture equivalent, moisture content at time of sampling, and relative wetness of surface soil from grazed and ungrazed farm woodlands.*

Experimental area No.	pH		Organic matter, %		Volume weight		Moisture equivalent, %		Moisture content at sampling time, percentage oven dry weight		Relative wetness	
	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed
I	6.57	6.55	5.59	9.41	1.24	1.01	27.3	33.2	8.2	11.7	20.5	28.4
II	7.07	7.23	2.25	6.50	1.32	1.02	13.5	28.1	8.2	10.9	16.7	23.1
III	5.13	6.98	8.05	7.65	1.03	0.85	25.5	30.1	14.6	22.4	31.6	25.4
IV	6.66	5.98	5.72	6.03	1.17	0.96	24.6	25.6	8.7	13.4	23.3	23.5
V	6.20	5.53	7.73	11.50	1.18	0.89	33.1	37.2	6.1	8.2	23.4	31.0
VI	6.13	6.83	7.48	4.76	1.18	0.95	22.3	20.7	6.2	6.9	33.5	23.0
VII	4.84	6.94	3.33	10.76	1.15	0.89	25.3	41.9	7.4	23.3	13.1	25.7
VIII	6.45	6.33	4.83	8.56	1.21	0.77	29.8	37.6	11.2	16.3	16.2	22.7
IX	6.26	6.94	5.68	7.26	1.08	0.96	27.3	35.1	16.1	21.1	20.7	20.6
X	6.61	5.93	8.17	8.48	1.16	0.99	33.6	41.2	9.3	10.3	24.3	20.5
XI	5.55	5.58	5.50	7.60	1.32	0.86	29.7	34.4	11.2	18.7	18.5	22.1
XII	4.86	4.76	4.57	4.65	1.22	1.11	38.1	43.3	5.2	6.3	12.0	10.7
XIII	4.79	4.30	8.79	13.95	1.00	0.78	46.4	51.2	10.7	14.2	18.9	27.3
XIV	6.27	4.32	9.03	11.35	1.14	0.88	42.2	51.8	10.7	9.6	21.4	21.9
XV	4.66	4.39	7.88	7.91	1.00	0.87	34.8	35.6	19.1	26.3	22.5	22.2
XVI	5.42	4.77	4.16	8.86	1.24	1.10	28.0	33.7	10.2	11.6	14.9	26.2
XVII	4.60	4.57	11.26	11.39	0.82	0.79	58.9	46.6	23.0	20.0	19.1	24.4
XVIII	4.35	4.12	5.15	6.38	1.32	0.89	35.9	35.6	4.1	7.2	14.3	17.9
Mean	5.69	5.67	6.40	8.50	1.15	0.92	32.0	36.8	10.6	14.4	20.3	26.1
Odds that difference is not due to chance alone	1:1		499:1		Infinite		216:1		832:1		31:1	

No important difference in pH occurred between the grazed and ungrazed soil, the averages being 5.69 and 5.67, respectively.

The organic matter content of the soil from the ungrazed woodland was significantly higher than that of the grazed areas. There are only two instances where the organic matter content of the grazed area exceeded that of the ungrazed, both occurring on Ontario loam in Wayne County.

The volume weight of the grazed soils was significantly higher than that of the ungrazed. The differences were not great, however, the means being 1.15 for the grazed and 0.92 for the ungrazed.

The moisture equivalent was higher in the case of the ungrazed soils. An examination of the individual figures indicates that this difference seems to be largely associated with the organic matter content. The finer textured soils, however, did exhibit higher values for the moisture equivalent.

The moisture content at time of sampling was higher in the ungrazed soils. Since it has been shown by Coile (6) that the organic matter content of soils influences the moisture equivalent considerably more than the wilting percentage, and since Veihmeyer (19) has shown a good correlation between the moisture equivalent and field capacity of soils, expressing the moisture content as relative wetness (percentage of the moisture equivalent) would seem more logical. The last column in Table 2 presents these figures. The mean difference between the grazed and the ungrazed soils is statistically significant.

As previously stated, aggregate and ultimate dispersion analyses were run on all samples. The data for the Ontario loams, Honeoye loams, Volusia silt loams, and Lordstown silt loams are presented graphically by area curves in Figs. 2, 3, 4, and 5.

The experimental area numbers constituting the data are as follows: Ontario loam, Nos. I, II, IV, V, and VI; Honeoye silt loam, Nos. IX, and X; Volusia silt loam, Nos. XI, XII, and XIII; and Lordstown silt loam, Nos. XVI, XVII, and XVIII. The values obtained for No. III were not included in the Ontario loam data because the grazed sample was sifted by mistake before analysis. Number XIV was not used in constructing the curve for the Lordstown soils because it had a thin coarse mull humus layer. It seemed desirable to include only mor humus layers with the Lordstown soils since it is the typical condition for this series. The data from the remaining soil types are not presented because the trends were similar to those shown.

The differences in state of aggregation were not as great as had been anticipated by observation. The soils from the ungrazed woodlands, however, were found to have a larger percentage of aggregates greater than 1 mm in diameter. In order to show these differences more clearly, the area of the curve to the right of a line drawn through the 1-mm point was measured with a planimeter. Since all curves were drawn to the same scale, these figures would represent the relative percentage of the aggregates greater than 1 mm in diameter. The same procedure was also carried out for the entire cross-hatched areas. The data are presented in Table 3.

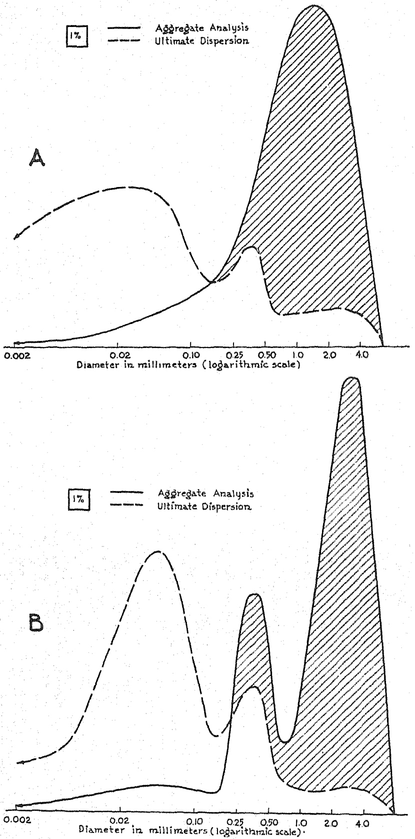

FIG. 2.—Average particle size distribution (area type of curve) for the Honeoye silt loam soils, with and without dispersion. A, grazed; B, ungrazed.

TABLE 3.—*Relative amount of aggregates greater than 1 mm in diameter.**

Soil type	Relative amount of aggregates greater than 1 mm in diameter		Percentage decrease of grazed as compared with ungrazed	Relative amount of aggregates (all size classes)	
	Grazed	Ungrazed		Grazed	Ungrazed
Honeoye silt loam...	92	132	30.3	152	153
Ontario loam.......	67	97	30.9	114	134
Volusia silt loam....	66	133	50.3	117	152
Lordstown silt loam.	47	71	33.8	121	118

*As measured by actual areas from Figs. 2, 3, 4, and 5.

These differences would have been greater had only the aggregates greater than 2 mm been considered.

The greatest degree of aggregation (considering only the material >1.0 mm in diameter) occurred in the Volusia and Honeoye soils, and the greatest relative decrease of the grazed as compared with the ungrazed occurred in the Volusia and Lordstown soils.

In order to find out if the pore size distribution of the soils differed under grazed and ungrazed conditions, duplicate samples of Volusia soil near Ithaca (experimental area No. XI) were obtained without appreciably disturbing the natural soil structure. The soil pores were filled with water and then increasing increments of tension were applied and the volume of water withdrawn by each successive tension was measured. The process was carried out using the apparatus described by Bradfield and Jamison (2). Equilibrium was not established at any tension, but a given tension was applied until not more than 0.02 cc of water was withdrawn during a 4-minute period. Approximately the same time intervals were used with the grazed and ungrazed samples and the same volume of soil constituted each sample. The results are presented graphically in Fig. 6. It can readily be seen that the only important difference occurred as a result of the application of the first tension. This indicates that any differences in pore-size distribution were concerned with pores larger than 100 microns in diameter.

The data for air temperature, soil temperature, light intensity, and relative humidity of atmospheric air are presented in Table 4. The grazed woodlands, when compared with the ungrazed had higher soil and air temperatures as well as higher light intensities, while the relative humidity of the air was lower.

DISCUSSION

It is not surprising that no consistent difference in pH existed between the grazed and ungrazed soils. The differences that did occur could often be attributed to variations in species composition of the forest stand, correlating fairly well with the theoretical calcium content of the foliage (5).

The higher organic-matter content of the ungrazed soils might be attributed to several causes. Although no actual measurements were

made of the amount of annual leaf-fall on the grazed and ungrazed areas, it seems extremely probable that the amount on the former was considerably less than on the latter. This might have resulted from a lack of a younger understory which hence could not have deposited any leaves. Furthermore, the crown density was reduced considerably due to the low vigor of the trees in the grazed areas, and, therefore, the amount of leaves falling on a given land surface was less. Also, because of greater wind velocity and less shrubby vegetation to hold leaves, there was a tendency for the litter to blow out of the grazed areas, or at least into the depressions. The amount of organic matter added by the dying grass roots was partially offset by the loss in amount of litter.

TABLE 4.—*Air temperature, soil temperature, light intensity, and relative humidity of atmospheric air in grazed and ungrazed farm woodlands.*

Experimental area No.	Air temperature, °C		Soil temperature, °C		Light intensity, percentage of full sunlight		Relative humidity, %	
	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed	Grazed	Ungrazed
I	25.0	23.9	24.2	20.0	9.5	1.6	78	81
II	25.6	25.0	21.1	20.0	18.9	2.4	71	75
III	27.2	25.6	23.0	21.0	15.6	9.0	61	71
IV	30.6	27.2	24.1	19.9	30.0	3.6	42	50
V	27.2	25.6	24.5	21.8	9.6	1.5	45	53
VI	29.4	25.6	27.2	21.5	22.0	2.4	41	53
VII	30.6	28.3	25.6	22.3	17.2	3.4	48	62
VIII	28.9	26.7	23.3	19.9	33.0	3.2	51	64
IX	27.8	25.5	22.5	20.3	8.8	1.3	58	75
X	20.0	15.6	23.8	15.1	23.0	1.5	54	77
XI	26.1	25.0	23.1	19.7	34.5	3.5	56	62
XII	27.2	26.7	25.6	21.2	22.8	3.0	53	61
XIII	27.8	26.7	23.1	19.8	14.7	2.5	45	64
XIV	25.0	23.3	21.5	17.5	26.0	4.4	54	74
XV	25.0	23.3	20.1	18.0	11.0	3.5	58	78
XVI	25.6	22.2	22.4	20.2	24.9	2.6	60	73
XVII	29.4	27.2	21.0	22.0	30.1	2.0	41	51
XVIII	29.4	27.2	29.2	21.1	27.1	3.2	49	59
Mean	27.1	25.0	23.6	20.1	21.0	3.03	53.6	65.7
Odds that the difference is not due to chance alone	Infinite		Infinite		Infinite		Infinite	

Morgan and Lunt (15) and Romell (16) have shown that the organic-matter content of the forest soils in the northeastern United States is considerably lower in the warmer, drier sections than in the cooler, more humid ones. Therefore, since slightly higher temperatures as well as somewhat drier conditions obtained in the grazed woodlands, it would logically follow that a lower organic-matter content would exist in the grazed soils under equilibrium conditions.

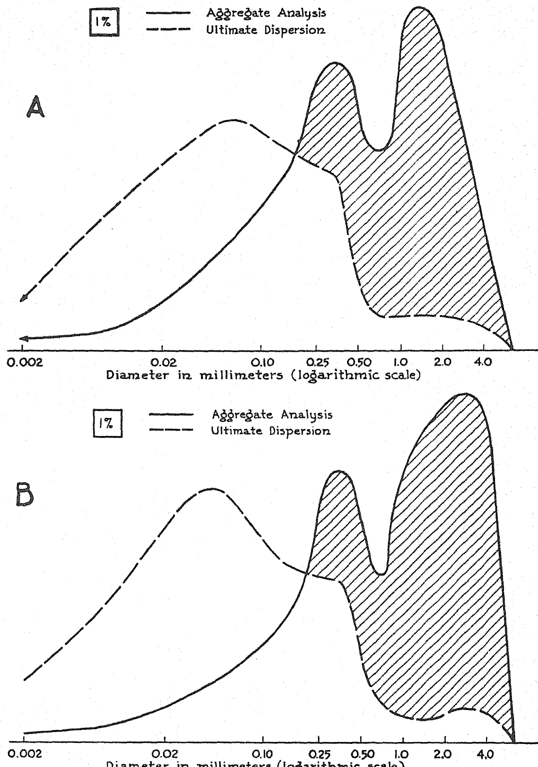

FIG. 3.—Average particle size distribution (area type of curve) for the Ontario loam soils, with and without dispersion. A, grazed; B, ungrazed.

The higher volume weight on the grazed soils might be explained on the basis of several combined influences, *viz.*, (a) the trampling effect of the cattle would tend to compact the soil, (b) the lower organic-matter content might cause an increase in the actual specific

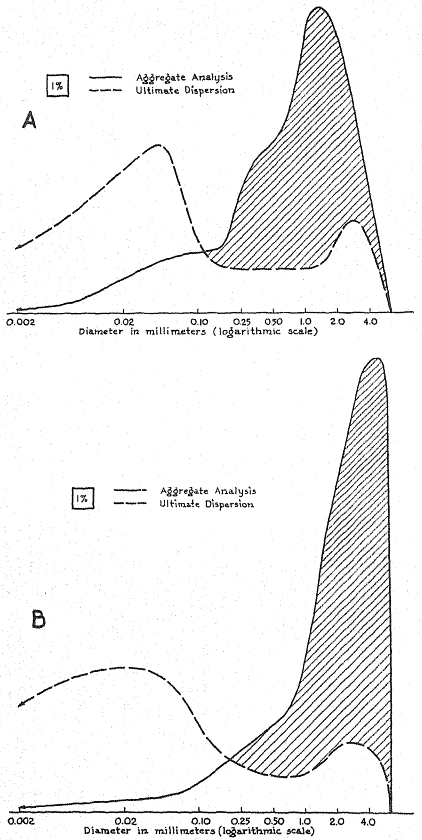

FIG. 4.—Average particle size distribution (area type of curve) for the Volusia silt loam soils, with and without dispersion. A, grazed; B, ungrazed.

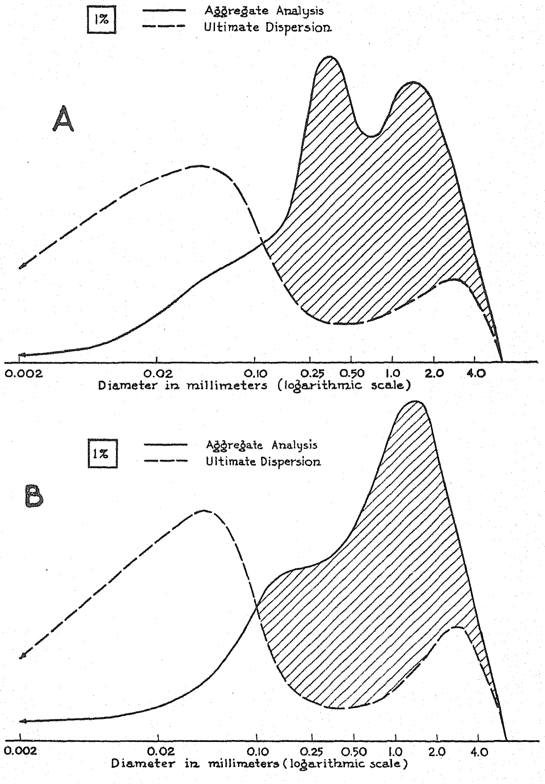

FIG. 5.—Average particle size distribution (area type of curve) for the Lordstown silt loam soils, with and without dispersion. A, grazed; B, ungrazed.

gravity of the soil as a whole and thus increase the volume weight, and (c) the lower percentage of the larger aggregates would be conducive to tighter packing of the soil and hence a reduction in pore space and an increase in volume weight.

Although Zon (21), Craib (7), and other workers have indicated that forest trees remove large amounts of water as compared with other types of vegetation, the fact is brought out by the figures presented in this paper, as well as those by Diller (11), that in spite of a decreased crown area the soil moisture content of the grazed woodlands was consistently lower than that of the ungrazed woodlands. Apparently the increased sunlight and wind velocity produce conditions predisposing toward high rates of both transpiration and soil surface evaporation. That the differences were not brought about by the high organic-matter content of the ungrazed areas is revealed by the fact that the differences were still significant when expressed as relative wetness. These differences are not confined to the surface

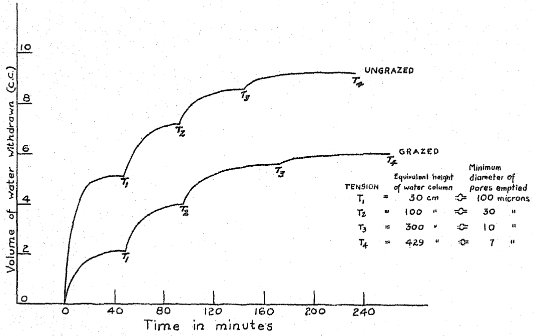

FIG. 6.—Volume of water withdrawn from grazed and ungrazed Volusia silt loam soil by the application of successive increasing tensions.

soil, but, according to Diller (11), extend well into the subsoil. The drier conditions of the grazed soil on sloping areas might be partially attributed to a relative increase in surface runoff on the grazed areas as compared with the ungrazed.

It is possible that the trampling of the cattle had considerable influence in decreasing the proportion of the larger aggregates. Another factor which may have been partially responsible for the differences, but on which no data were obtained, is the abundance and activity of earthworms. In all the ungrazed areas, on which the humus layer type was a coarse mull, signs of intense earthworm activity were noted. Under the grazed woodland areas, observations indicated a lessened intensity of earthworm activity, and in certain cases it was difficult to find any earthworm castings. Those working with forest soil humus layers (17, 13) have generally agreed that the well-developed crumb structure of coarse mull was due primarily to the activity of earthworms. Since the grazed soils are drier and warmer and hence provide a less favorable environment for earthworms, it

would not seem improbable that their decreased activity might be partially responsible for the small number of the larger aggregates. In further support of this, the Lordstown soils, in which no earthworms were found, showed the least total aggregation of all soil types under the ungrazed condition.

The preliminary results obtained in this study would indicate that the soils well supplied with calcium, such as Honeoye and Ontario, held their original surface soil structure under grazing to a greater degree than the more acid Volusia and Lordstown soils. The limited number of observations in this study, however, would not permit any generalizations on this point.

The comparatively large amount of light reaching the ground in the grazed woodlands can be attributed to two principal causes. The understory was missing due to the fact that for 30 years or more no reproduction had been allowed and the crown density was relatively low because of low vigor, as well as the fact that some trees had usually been removed and no young trees were present to occupy the empty spaces. The extra light was undoubtedly the principal cause for the increased soil and air temperatures, and was probably responsible in part for the lower moisture content on the grazed areas.

The high relative humidity under the ungrazed conditions might be ascribed partially to the following factors: The soil was more moist, there were more leaves transpiring water, and the wind movement was considerably decreased.

It is not within the province of this study to determine which of these differences attributed to grazing are the most influential in decreasing the productivity of farm woodlands. Undoubtedly a combination of factors is responsible. We can make the general statement that grazed woodlands as compared to ungrazed ones tend to have a lower organic-matter content, and hence lower water-retaining properties. The volume weight of the soil is generally higher while the proportion of soil aggregates greater than 1 mm in diameter is lower. The actual amount of available soil moisture is usually lower, while the air and soil temperatures are higher and the relative humidity is lower. Considering the fact that forest soils in the humid Northeast are usually moist and cool and the air surrounding the trees is usually rather humid, it is not surprising that the changes associated with grazing reported in this paper cause a less favorable environment for most native forest trees.

SUMMARY

The results of a study of soil and climatic conditions in 18 paired grazed and ungrazed woodland areas can be summarized as follows:

1. No significant differences in pH of the surface soil were found.
2. The soil organic-matter content was higher under the ungrazed conditions, averaging 8.5% as compared with 6.4% for the grazed areas.
3. The volume weight of the grazed soils averaged 1.15, while the ungrazed soils averaged 0.92.
4. The moisture equivalent was higher under the ungrazed conditions and correlated well with soil organic matter content.

5. The moisture content of the soil was highest on the ungrazed areas, whether expressed as percentage of oven-dry soil or as relative wetness.

6. Air and surface soil temperatures were highest in the grazed woodland areas.

7. The amount of light penetrating the forest canopy was much greater in the grazed woodlots, averaging 21% of full sunlight as compared with only 3.03% under the ungrazed conditions.

8. The relative humidity of the air was highest under the ungrazed conditions, being 65.7% as compared with only 53.6% for the grazed woodlands.

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PRELIMINARY RESULTS ON SEED SETTING IN RED CLOVER STRAINS[1]

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THERE has been considerable interest in the posibility of using some of the European short corolla tube, or so-called "bee clover," strains of red clover in this country. It has been thought that these strains would be more attractive to honey bees because the shorter corolla tubes would facilitate the collection of nectar. A greater attractiveness for honey bees would presumably result in more pollination in the field and, consequently, an increase in seed setting. While generally recognized that it would be unlikely that any of these strains would be highly satisfactory in themselves, it was thought that they might be of value in a breeding program aimed at more dependable seed production.

Preliminary studies on seed setting with three American and three European strains have been conducted during the past two seasons. The American strains included a well-adapted strain from Ohio, the Emerson Iowa strain, and the variety known as Kentucky 101. The European clovers included the Wilson white-blossomed type, the Swiss No. 944, and the Zofka short corolla tube strains. Corolla tube lengths in the different strains as determined in both the first and second crops during the 1939 season are given in Table 1.

TABLE 1.—*Corolla tube length and variability in six red clover strains, 1939.*

Variety	Number of florets	Average length in mm	Standard error	Coefficient of variation, %
Kentucky 101	490	9.09	±0.115	5.50
Wilson (white)	150	8.44	±0.347	10.07
Emerson (Iowa)	490	8.42	±0.135	8.19
Ohio	490	8.35	±0.141	7.38
Swiss 944	250	7.92	±0.161	6.44
Zofka	490	6.93	±0.199	12.55

These values were obtained by measuring the distance from the base of the corolla to the upper limit of the closed portion of the tube as indicated by a faint mark at the base of each wing process.

Kentucky 101 had the longest corolla tubes and Zofka the shortest, the difference between these two being 2.16 mm which is statistically

[1]Cooperative investigations of the Iowa Agricultural Experiment Station, Ames, Iowa, and the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Iowa Agricultural Experiment Station Journal Paper No. J-697, Project 658. Received for publication January 6, 1940.

[2]Research Associate Professor, Iowa Agricultural Experiment Station and Agent, Bureau of Plant Industry, and Research Assistant in Forage Crops, Iowa Agricultural Experiment Station, respectively. The authors are indebted to Dr. E. A. Hollowell, Senior Agronomist, Division of Forage Crops and Diseases, for furnishing seed and helpful suggestions invaluable in conducting these experiments.

highly significant. It is apparent from the data that the Wilson (white-blossomed) and Zofka strains were considerably more variable than the others.

In 1938 seed yields were determined in the Zofka, Swiss, and Ohio strains. An equal number of heads was harvested from each plot at different times from July 28 to October 4. Seed yields reported in grams of seed per 100 heads are given in Table 2. Statistical analyses show that the Ohio strain is significantly higher in yield than either the Swiss or Zofka short corolla strains.

TABLE 2.—*Seed yields in red clover strains, 1938.*

Strain (500 heads each)	Grams of seed per 100 heads
Zofka	2.75
Swiss 944	2.94
Ohio	4.63

During the 1939 season a more elaborate study was conducted. Heads were collected during August and September and the number of seeds per head determined. Two colonies of bees had previously been located near the red clover plots so that honey bees would be plentiful for pollination work. Results of this study are given in Table 3.

TABLE 3.—*Seed setting in red clover strains, 1939.*

Harvest date	No. of heads	Average number of seeds per head				
		Ohio	Emerson (Iowa)	Kentucky 101	Wilson (white)	Zofka
Aug. 21..	500	79	—	—	—	20
Aug. 23..	150	—	73	76	70	47
Aug. 25..	300	—	70	59	48	24

The data indicate, as in 1938, a significantly lower seed production in the Zofka short corolla tube variety.

A second and more detailed study was made using a smaller number of heads. The number of florets per head, number of seeds per head, and the percentage of florets setting seed were determined. These data are presented in Table 4, 25 heads of each strain being the number examined in each sample.

The results indicate that not only were fewer seeds produced by the Zofka short corolla strain, but that this strain actually had a significantly lower percentage of seed set.

Observations on bee activity in all of the plots showed that, while the number of bees present varied from day to day, and from hour to hour, there were usually considerably more honey bees than bumble bees visiting the flowers. It was noted further that, in the Zofka plots, honey bees and bumble bees were found in approximately equal numbers, while in plots of the Emerson Iowa strain there were usually twice as many honey bees as there were bumble bees. In 17 different counts throughout the blooming period there were 5 times as many

honey bees and 3 times as many bumble bees on the Emerson plots as were present on the Zofka plots. While there were some more flowers present in the Emerson plots, the difference in numbers of flowers was not proportional to the great difference in bee activity noted. The lower percentage of seed setting in the Zofka strain would seem to be a logical result of less bee activity.

TABLE 4.—*Number of florets per head, seeds per head, and percentage of seed set in red clover.*

Harvest date	Strains of red clover			
	Emerson (Iowa)	Kentucky 101	Wilson (white)	Zofka (short corolla)
	Average Number of Florets Per Head			
Sept. 8.......	106	90	106	81
Sept. 12......	106	101	90	74
Sept. 25......	94	88	90	70
Sept. 25......	102	82	92	75
Average....	102.0	90.2	94.5	75.0
	Average Number of Seeds Per Head			
Sept. 8.......	83	74	84	57
Sept. 12......	86	79	68	45
Sept. 25......	66	58	59	47
Sept. 25......	69	59	58	47
Average....	76.0	67.5	67.5	49.0
	Average Percentage of Florets Setting Seed*			
Sept. 8.......	78	83	70	70
Sept. 12......	81	78	76	61
Sept. 25......	70	66	66	67
Sept. 25......	70	69	63	62
Average....	74.8	74.0	68.8	65.0

*In percentage of florets setting seed a difference between variety means of 6.65 is necessary for significance at the 5% level.

It appears then that Zofka red clover offers no advantage from the standpoint of attractiveness to honey bees. On the contrary, there is considerable evidence to indicate that the American strains are more attractive to honey bees than is Zofka. It is known that bees visit red clover to collect pollen as well as nectar. While they may carry both, it is likely that at times they are concerned principally with the collection of pollen. Under such circumstances the length of corolla tubes would be unimportant. Bees would tend to visit those heads where pollen was most abundant whether or not they could actually reach the bottom of the corolla tube to obtain all of the nectar present. While no data were obtained, daily observations made while hand pollinating a large number of heads indicated that the American strains probably furnished a much better source of pollen than did the Zofka.

The data presented in this study indicate both less honey bee activity and less seed production in the Zofka strain than in the American strains. Contrary to popular expectations, the length of corolla tube did not seem to be a factor of importance under the conditions of this experiment. It is suggested that possibly the abundance of pollen, secretion of nectar, or concentration of nectar may have been of more importance in determining the attractiveness of red clover strains to honey bees. The data on seed setting indicate that with the well-adapted American strains there would seem to be excellent potential possibiltiies for high yields of seed when conditions are favorable for abundant bee activity.

NOTES

SUGGESTED DESCRIPTIVE TERM "NATURALIZED" FOR ESTABLISHED EXOTIC ECOTYPES OF HERBAGE PLANTS

THE need of a descriptive term for general definition of exotic pasture and hay plants now well established through natural selection and long-continued self-perpetuation is evident to investigators working with herbage plants. This is particularly true of white clover, Kentucky bluegrass, and certain other legumes and grasses that have made up the herbage flora for many years without being artificially reseeded. Such plants may or may not completely or even partially represent the prototypes for in most cases the prototypes are not definitely known. Depending upon the method of pollination or reproduction; the action of certain limiting factors of the environment occurring at periodic intervals, seasonal or otherwise, and the aggressiveness of the plants, populations may consist of several distinct morphological and physiological forms of the same species representing rather a wide ecotypic range. These plants are not native or wild, these terms being synonymous, nor are they spontaneous even though they may seem to appear spontaneously. They are "naturalized" plants, being the surviving progeny of chance or planned plant introductions many of which occurred during the early settlement of this country.

The term "naturalized" is suggested with reference to such plants. In connection with the use of the term "naturalized" it would be essential that the state of origin be given. For example the state of origin could be used in a modifying phrase as "naturalized" white clover of Louisiana or as an adjective such as Louisiana "naturalized" white clover. Since this term is widely used by systematic botanists with the same meaning, its adoption by agronomists would lead to a more complete unity of usage. Any criticism of the term "naturalized" with suggestions regarding other appropriate terms is solicited. —E. A. HOLLOWELL, *Bureau of Plant Industry, Division of Forage Crops and Diseases, U. S. Dept. of Agriculture, Washington, D. C.*

FOREST SERVICE RANGE RESEARCH SEMINAR

PRESENT knowledge of "grassland" agriculture in America is both meager and poorly organized. The building of a suitable and adequate body of information for showing what constitutes intelligent forage production and for guiding the husbandry of areas to be utilized by grazing has for some time loomed as a major agronomic and ecologic need. Year by year this need has grown more urgent, and judged by present trends, it is not likely to decrease, but on the contrary will doubtless expand to great proportions.

This demand has not been ignored by technical and professional men. More research has been initiated; cultural programs and demonstrations inaugurated; a general awakening has occurred; and groups and individuals are beginning to appraise the basic philosophy of range land husbandry and the programs designed to meet and solve

the problems in this field in a more objective and critical manner than ever before. In keeping with this on-coming expansion in demand for adequate information regarding range forage and range land use and management, a conference of major interest was held July 10–22, 1939, at the Great Basin branch of the Intermountain Forest and Range Experiment Station, near Ephraim, Utah, by the U. S. Forest Service, to take stock of objectives, plans, procedures, and technics applicable to range research problems.

The problems most carefully analyzed at the conference were those dealing with (1) the development of sound research programs based on regional and local problem analysis; (2) research methodology, including experimental design and statistical analysis; and (3) vegetation problems such as forage growth and production, vegetative changes, trends and conditions, utilization of the forage crop and artificial revegetation. Problems dealing with multiple range land use, handling livestock on the range and animal nutrition were also included, as well as those pertaining to publications, recruiting personnel, cooperation with other research agencies, and the need for, and the means of accomplishing, intelligent range extension education.

As in other fields, many of the plans for the early pioneer range investigations largely dealt with local needs and empirical aspects of the range problems. In the recent past an effort has been made to analyze range problems more thoroughly and so to state objectives and to develop the design of the experiments in order that the findings will have more general application and conclusions be founded more nearly on basic principles. The seminar re-emphasized this need and recommended that in the future such a systematically organized program with its necessary procedure be required for all major range research projects.

Papers and discussions pointed out that all future experiments aiming at important conclusions cannot escape being criticized as to whether they embrace acceptable experimental designs involving either hidden or direct replications, randomization, and check treatments. Some research designs and procedures now in operation might also be greatly improved by being slightly revamped in such a way as to make them conform more closely to acceptable designs. Planning research studies in such a way that they are statistically sound is strongly emphasized, with the caution, however, that statistics be regarded as a tool to assist in planning the design and analyzing the data for significant conclusions rather than as an end in itself. Owing to the necessity in range research of obtaining in many cases approximations rather than precisely determined measurement data, the ecologists and agronomists of the conference felt that over-complicated designs and ultra-refined statistical technique had as yet best be avoided.

An analysis of the difficulties encountered in vegetational studies uncovered the acute need for more refined methodology to be used in obtaining range inventories, forage estimates, and utilization surveys. There is also insufficient information regarding the place of enclosures and permanent plots in the experimental design and regarding what

kind of data to take from them. The various intensive methods of studying vegetation are also not fully adequate in their present state of development. Range researchers must always strive to improve the methods and techniques of obtaining more precise measurements and accurate data without losing sight of the ever-constant need of finding at least partial solutions to the economic and biological problems of the range.

The distressing need for more adequate supplies of range forage makes patent the urgency of obtaining new and significant information on how to increase forage production, in learning the nature and degree of utilization to which forage species might, without injury, be subjected, and in establishing the climatic and soil conditions to which the various forage species are adapted. In the important field of artificial range revegetation whole blocks of new information are required, not only regarding adaptability of species, but also as to when, how, and what to reseed; how best to cover the seed; in many cases how to deal effectively with undesirable or low-value vegetation on the ground; and from a practical point of view, how to devise effective and economical methods of artificial revegetation that will produce new stands of vegetation at costs sufficiently low to make the revegetation process a feasible one. Likewise, the whole problem of range rehabilitation by better grazing management still needs thorough and incisive study.

It is definitely recognized that information regarding the nutritive values of the various range forages is a critical need, and one on which the comparative value of different ranges must be based. Little information is now available regarding the chemical composition and nutritive value of range forage species at different stages of maturity; nor is practically anything known of the digestibility of these forages at present. Much basic chemical and physiological research is required before an intelligent program of forage requirements and utilization can be established. For example, our information is scant indeed regarding the manner in which intensity of previous use, effects of weathering on mature forage, and loss of rich top soil influence the nutritive value of the forage.

Two supplemental phases of the conference were week-end trips and illustrated evening lectures. The trips consisted of an excursion to the Desert Experimental Range, where practical grazing experiments are under way; one to the terraced and artificially reseeded watersheds, between Salt Lake City and Ogden that have proved effective in flood control; and others to nearby national forests and national parks of southern Utah and Arizona embracing varied range conditions.

Four evening lectures also fortified the technical program and discussions: (1) The 1938 European Grassland Conference, W. R. Chapline, chief of Forest Service range research; (2) The role of geology in interpreting watershed problems, R. W. Bailey, director, Intermountain Station; (3) The ecological plant changes in southwestern Utah, Dr. W. P. Cottam, botanist, University of Utah; and (4) The historical and economic development of Utah since settlement, Dr. W. L. Wanlass, Utah State Agricultural College.

Attendance at the conference included the directors, range research leaders, and most of the men engaged in range research from the six western Forest Service forest and range experiment stations; the assistant regional foresters in charge of range management administration in western national forest regions; Regional Forester C. N. Woods of the Intermountain Region; Director E. L. Demmon of Southern Forest Experiment Station; and Washington officials in charge of range research, range management, and wildlife management.—GEORGE STEWART, *Intermountain Forest and Range Experiment Station, Ogden, Utah.*

BOOK REVIEWS

PLANT PHYSIOLOGY

By E. C. Miller. New York: McGraw-Hill Book Co., Inc. Ed. 2, XXXI+1201 pages, illus. 1938. $7.50.

THE second edition of this excellent book on plant physiology continues the effort so successfully made in the first edition to present an advanced text book in plant physiology and to include contributions from American and English plant physiologists along along with those from Continental workers. The subject matter still deals solely with the green plant, omitting fungi.

The new edition is really more than a text book for advanced students—it becomes a handbook of plant physiology and serves as a reference source for an amazing range of topics. Some conception of the addition of material in the 7½ years intervening between the appearance of the two editions may be gathered from the fact that there are 301 additional pages— an increase of one-third. There are over 3,600 individual authors cited in the author index and the subject index lists over 4,500 individual items. These two features of the book alone make it an invaluable addition to any library, office, or laboratory where matters of plant physiology are of interest.

The new material that has been added quite naturally reflects the more recent contributions in plant physiology. They include, for example, a more complete discussion of the general physical and chemical properties of the cell wall; absorption of elements, now including copper, zinc, iodine, and selenium; nitrogen metabolism; translocation of organic compounds; enzymes; growth-promoting and growth-inhibiting substances; and vernalization. (H. B. T.)

FIELD PLOT TECHNIQUE

By Warren H. Leonard and Andrew G. Clark. Minneapolis, Minn.: Burgess Pub. Co. II+271 pages, mimeoprint, fabricoid covers. 1939. $3.25.

OF the many publications on statistical procedure published in recent years this joint product of the Department of Agronomy and Mathematics of the Colorado State College should be especially welcome to the student and teacher of field plot technic. The material which was developed as a lecture course for seniors and graduate students is especially rich in fundamental background and specific examples of various procedures, as well as extensive references in each chapter, questions for discussion, and problems for solution.

It covers the subjects of frequency distributions and methods of testing significance, correlation, analysis of variance and coveriance, and regression. Part 3 takes up plot technic itself and covers such subjects as soil heterogeneity, plot characteristics, design of experiments as applied to various types of agronomic research, theory of sampling, complex experiments and confounding. It ends with a discussion of mechanical procedure for field experimentation.

A 16-page appendix of useful tables concludes the presentation followed by a subject index. The multigraphing seems excellent, giving a clear, and easily readable text, well arranged and clearly presented. (R. C. C.)

AGRONOMIC AFFAIRS

STATE REPRESENTATIVES

PRESIDENT F. J. Alway of the American Society of Agronomy and President W. H. Pierre of the Soil Science Society of America, acting jointly, have designated the following persons to serve as representatives of the two societies in their respective states for the purpose of procuring new members. The representatives for the American Society of Agronomy have also been asked to serve as "correspondents" for this JOURNAL, supplying items of general agronomic interest on changes in personnel, new lines of work undertaken in their section, and all other items that might be of interest to readers of the JOURNAL. The appointments are as follows:

State	American Society of Agronomy	Soil Science Society of America
Alabama	J. W. Tidmore	J. W. Tidmore
Arizona	Ian A. Briggs	W. T. McGeorge
Arkansas	C. F. Simmons	C. F. Simmons
California	B. A. Madson	W. P. Kelley
Colorado	W. H. Leonard	H. W. Reuszer
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Delaware	G. L. Schuster	H. C. Harris
District of Columbia	Chas. E. Kellogg	Chas. E. Kellogg
	M. A. McCall (Crops)	
	E. A. Norton (S.C.S.)	E. A. Norton
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State	American Society of Agronomy	Soil Science Society of America
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Nevada	V. E. Spencer	V. E. Spencer
New Hampshire	F. S. Prince	F. S. Prince
New Jersey	H. B. Sprague	R. L. Starkey
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New York	Richard Bradfield	Richard Bradfield
North Carolina	J. F. Lutz	J. F. Lutz
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Ohio	R. M. Salter and L. D. Baver	R. M. Salter and L. D. Baver
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Tennessee	O. W. Dynes	Eric Winters
Texas	Ide P. Trotter	Ide P. Trotter
Utah	R. H. Walker	R. H. Walker
Vermont	A. R. Midgeley	A. R. Midgeley
Virginia	S. S. Obenshain	S. S. Obenshain
Washington	E. G. Schaffer	S. C. Vandecaveye
West Virginia	Edward H. Tyner	Edward H. Tyner
Wisconsin	Emil Truog	Emil Truog
Wyoming	T. J. Dunnewald	T. J. Dunnewald

A SCARCITY OF MANUSCRIPTS

FOR the first time in many years the JOURNAL is experiencing a shortage of suitable papers for publication. Improvement in the financial status of the Society during the past two or three years has made possible somewhat more expeditious handling of manuscripts, with the result that papers are moving along toward publication at a more rapid rate.

With the new Editorial Board now functioning smoothly, papers are being reported upon promptly and it would be highly desirable if the editors could see more manuscripts. All members of the American Society of Agronomy and of the Soil Science Society of America are eligible to use the pages of the JOURNAL for publication.

"AMERICAN FERTILIZER PRACTICES"

THE NATIONAL FERTILIZER ASSOCIATION has published under the above title a report of a survey among 32,000 farmers in 35 states on the use of commercial plant food. The survey was conducted by representatives of 65 member companies during the fall and winter of 1938–39.

The report is printed, is paper covered, is illustrated with numerous charts, many of which may be redrawn to show state instead of national figures, and is well indexed. A limited number of copies are available at $1.00 each, with special prices for agricultural workers. Communications should be addressed to the National Fertilizer Association, Investment Building, Washington, D. C.

The purpose of the publication is "to present facts informative both to the fertilizer industry and to the great body of agricultural workers of the country, including the staffs of agricultural colleges and experiment stations, extension services, the U. S. Dept. of Agriculture, country agricultural agents, vocational agriculture teachers, editors of farm journals, and others."

BIBLIOGRAPHIES OF THE LITERATURE ON THE MINOR ELEMENTS

THE third edition of the "Bibliography of References to the Literature on the Minor Elements", published February 1, 1939, by the Chilean Nitrate Educational Bureau, contained 4,628 abstracts and references, in a volume of 488 pages.

Owing to its size, it is not practical to continue publication of complete editions of the Bibliography, especially since the volume of material becoming available makes it desirable to publish more frequently. Accordingly, Supplement No. 1, to be published shortly, will contain about 700 abstracts and references, noted since publication of the third edition.

It is planned hereafter to publish supplements at intervals of approximately one year.

A Botanical Index is now available for the third edition and is also being included in the supplements.

NEWS ITEMS

DR. JOHN B. PETERSON, Assistant Professor of Soils at Iowa State College, has been granted leave of absence and is studying as a National Research Fellow in Geology and Geography under the guidance of Dr. W. P. Kelley at the University of California.

DR. FIRMAN E. BEAR was named head of the Department of Soils at the New Jersey Agricultural College and Experiment Station and Professor of Agricultural Chemistry at Rutgers University, effective January first. Doctor Bear has also been named Editor of SOIL SCIENCE.

THE ANNUAL meeting of the Canadian Seed Growers' Association will be held at the University of Manitoba, Winnipeg, Man., June 17 to 19. Mr. W. T. G. Wiener of Ottawa is Secretary-Treasurer of the Association.

DR. GILBEART H. COLLINGS, Professor of Soils at the Clemson Agricultural College, has been recently appointed consulting editor for a new series of agricultural textbooks which will be published by the Blakiston Company of Philadelphia, Pa.

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A COMPARISON OF YIELDS AND COMPOSITION OF SOME ILLINOIS PASTURE PLANTS[1]

R. F. FUELLEMAN AND W. L. BURLISON[2]

AN approach to a solution of some of the problems of pasture yield and management are chemical analyses of forages. Chemical analyses serve the dual purpose of illustrating the nutritive value of pasture crops and species and their actual acre yields of minerals, proteins, and carbohydrates. The protein and minerals contained in forage materials are probably a more rational basis for acre-yield estimations than are dry matter determinations. A number of pasture species have been used for experimental farm pastures at Urbana, Illinois. The Agronomy and Animal Husbandry Departments of the University of Illinois have cooperated in obtaining data from 5- and 10-acre fields of grasses and legumes used for pasturing beef cattle and sheep. In this paper the yields and chemical composition of Reed canary grass (*Phalaris arundinaceae*), Kentucky bluegrass (*Poa pratensis*), orchard grass (*Dactylis glomerata*), and smooth brome grass (*Bromus inermis*) are presented and some comparisons made.

Trends in consumption of brome grass, Reed canary grass, Kentucky bluegrass and orchard grass seem to indicate that, while all are eaten readily by most types of livestock, brome grass is apparently somewhat more palatable. This statement should not be made without qualifications. There are times during the grazing season when animals indicate little preference among species, but not for sustained periods. When consumption records covering a number of years were examined, it was found that there was a marked and sustained seasonal increase in consumption of brome grass over that of other grasses. A higher ratio of consumption to production occurred with brome grass than the other species. Undoubtedly the stage and rapidity of growth, chemical composition, seasonal effects, and many other factors are responsible for apparent differences in palatability. The term palatability expresses the relative taste of materials as indicated by animal preference, although that which may be palatable to one animal may not be acceptable to another of the same type.

[1]Contribution from the Department of Agronomy, Illinois Agricultural Experiment Station, Urbana, Ill. Published with the approval of the Director. Received for publication December 26, 1939.

[2]First Assistant in Agronomy and Head of Agronomy Department, respectively.

Chemical analyses of forages are an aid in the interpretation of pasture experimental results as well as an indication of apparent palatability. They serve as a basis for comparison of the nutritive value of forages and the yield of digestible nutrients. The quantity of protein does not necessarily indicate its quality or digestibility; however, it is true that most high protein forages are apparently more palatable and nutritious than those containing less protein. Similarly, the percentages of phosphorus and calcium are indicators of nutritive value, but this does not mean that they are entirely available to the animal. The percentages of protein, or of minerals, in a sample of forage cut on any given date may vary considerably in comparable samples of the same species. This does not imply errors in analysis, in sampling, or differences due to soil heterogeneity. It is reasonable to assume that the forage itself may be undergoing changes brought about by the synthesis of de-synthesis of materials.

This paper presents briefly some of the results obtained from experimental pastures located at Urbana, Illinois, for the years 1935 to 1937, inclusive.

METHODS

A description of pasture sampling methods used at the Illinois Experiment Station has been published,[3] but it is included in this paper for the convenience of the reader.

Metal cages were used to protect the sample areas from grazing. The cages were constructed from ⅜-inch iron rods welded together to form a frame 4 by 4 feet square by 18 inches high. The corner rods extended 12 inches beyond the bottom of the cage and provided anchorage. The top and sides were covered with heavy 2 by 6 inch mesh woven wire welded to the frame.

A definite procedure was followed in placing the cages. The pastures were divided by imaginary lines into three parts and one set of two cages placed in each part. Three samples were taken from each section of the field on each sampling date. They were designated as "A", "B", and "C", the different sections of the field designated as 1, 2, and 3, so that samples from the first section would be designated as "1A", "1B", and "1C". The "A" samples consisted of herbage plucked or clipped from beneath a cage which had been placed over a representative grazed area at a previous sampling date or when the cattle were turned in. The sample harvested from a representative grazed area was designated as "C", or residual growth, while sample "B" was composed of the herbage which was harvested from beneath the cage placed on the "C" area on the previous sampling date. "B" is the total growth since the previous sampling date. The use of "A", "B", and "C" samples allows for two methods of computing yields and consumption, which for convenience have been termed the "A-C", or "A" method, and the "B" method. Obviously, in using these two methods in making computations, a difference in yield and also in consumption occurs. This is not an error due to sampling, but merely an arithmetical difference. This difference varies with the species of plants present in a pasture. For example, in a pasture containing a high percentage of legumes, the "B" method will usually indicate a much larger yield than the "A" method. Differences occurring between the two methods on gramineous pastures are small, with some exceptions, and the yields more nearly

[3]FUELLEMAN, R. F., and BURLISON, W. L. Pasture yields and consumption under grazing conditions. Jour. Amer. Soc. Agron., 31:399–412. 1939.

approximate each other. Apparently the difference is due to the morphological responses of plants after cutting. Grasses tend to send out new growth from rhizomes and the tiller buds near the soil surface. A legume such as alfalfa sends up new aerial shoots which, when protected from grazing, will greatly increase the yield.

The authors do not presume to select the method which is the more accurate representation of the actual yield from a given pasture. The experience of several seasons sampling seems to indicate that the method used is dependent on the type of forage and the season. Unless a large number of samples are obtained on each sampling date a number of negative yield figures may occur, especially in a system of random sampling. Using the "B" method eliminates the presence of negative yield figures regardless of the condition of the turf or the number of samples or the use of random samples. Results from the use of both the "A" and "B" methods are included so that the reader may judge for himself the more preferable system.

Chemical analyses were made on the "A", "B", and "C" samples. The methods of obtaining samples for analysis have already been described by the authors.[4] Analyses for protein, calcium, and phosphorus are shown in Tables 2, 3, 5, 6, 7, 9, 10, 11, 13, 14, and 15. A few analyses were made for crude fiber, nitrogen-free extract, and fat, but the data are not sufficiently complete for comparisons.

Pastures from which the data were obtained are in all cases practically pure stands of grass. Periodical examination of the forage by hand separations, or other commonly used methods, showed that the brome grass was approximately 87% pure, the Reed canary grass 98%; the Kentucky bluegrass 90 to 98%, and the orchard grass 98%. The influence of other species on the chemical composition is negligible.

DISCUSSION OF RESULTS

A portion of the yield data have been published, but they were expressed as the average of the "A" and "B" methods of sampling. In this paper the resulting "A" and "B" yields are not averaged, but each is given as separate figures.

REED CANARY GRASS

Yields of Reed canary grass for 1935 were not obtained as this field was not used as an experimental pasture. Table 1 shows "A" and "B" total yields for 1936 and 1937, and period yields during these years. Yields of dry matter in 1936 exceeded those of 1937 due to mechanical disturbance of the field in 1937. The season of 1936 was marked by excessive heat and periods of drouth, neither of which apparently was a serious factor in the final results. Yields as calculated by the "A" and "B" methods, respectively, in 1936 were 6,426 and 4,382 pounds of dry matter, a difference of approximately 2,000 pounds. The explanation for this difference is in the very slow recovery of growth of the "B" area during the second sampling period. Recovery was retarded in this period, May 25 to June 25, by dry, hot weather. The "A" growth did not suffer materially. Although there was a moisture deficiency, there were sufficient actively photosynthesizing leaves and stems to make the canary grass productive. During the cool months of late fall this tendency is reversed as

[4] *Loc. cit.*

TABLE 1.—*Reed canary grass yields of oven-dry matter per acre for 1936 and 1937 by "A" and "B" methods of calculation.*

1936			1937		
Cutting date	Period yields dry matter, lbs. per acre		Cutting date	Period yields dry matter, lbs. per acre	
	"A"	"B"		"A"	"B"
May 26	2,323	2,323	May 4	1,000	1,000
June 26	2,422	307	June 17	3,263	1,523
July 21	260	129	June 23	1,023	0
Aug. 24	958	760	July 16	1,515	806
Sept. 15	463	863	Aug. 13	− 986	94
			Sept. 13	939	139
			Oct. 30	−1,779	233
Total seasonal yield	6,426	4,382		4,975	3,795

between "A" and "B" yields. The "B" yields often exceed "A" yields for the same periods. Obviously the light, moisture, and temperature relationships are apparently less seriously affected in "B" areas than in "A" areas. The latter usually have a matting of dry vegetational material during this period, particularly Reed canary grass. "B" areas are usually free of accumulations of these materials. In 1937 the discrepancy between the "A" and "B" yields of dry matter was less pronounced.

Chemical analyses for protein, calcium, and phosphorus of "A", "B", and "C" samples for 1936 and 1937 are shown in Tables 2 and 3, respectively. All calculations were made on a water-free basis.

TABLE 2.—*Reed canary grass the 1936 protein, calcium, and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
June 26	8.47	12.63	5.77	0.252	0.367	0.189	0.251	0.359	0.182
July 21	6.61	19.07	4.93	0.298	0.375	0.183	0.225	0.477	0.249
Aug. 24	7.21	14.70	7.01	0.248	0.304	0.223	0.310	0.533	0.341
Sept. 15	13.51	12.60	9.46	0.321	0.270	0.239	0.410	0.400	0.332

Protein content of the "A", "B", and "C" samples of forage usually is highest during the early part of the season and declines steadily as the season progresses. The "B" samples invariably are high in protein because it is young green forage. "A" samples are intermediate between the "B" and "C" forages in protein content. "A" samples combine new growth plus residual material and obviously will be lower in protein. "C" samples, or residual growth are usually lowest, and Reed canary grass analyses for 1936 followed this general trend. A similar trend is found in the calcium and phosphorus content of the

TABLE 3.—*Reed canary grass the 1937 protein, calcium, and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 6	——	22.69	——	——	——	——	——	0.435	——
June 17	9.07	17.83	6.13	0.244	0.258	0.149	0.269	0.366	0.255
July 16	——	12.91	6.06	——	0.265	0.164	——	0.365	0.255
Aug. 13	7.44	15.88	5.24	0.222	0.314	0.176	0.273	0.376	0.289
Sept. 13	7.13	15.01	5.37	0.223	0.304	0.199	0.307	0.361	0.260
Oct. 30	6.12	14.81	3.93	0.181	0.370	0.108	0.231	0.309	0.175

"A", "B", and "C" forages. Variation between "A" and "C" samples is less marked. It is interesting to note the tendency for the protein, calcium, and phosphorus content in the "A" and "C" forages to increase as the season advances. This is again an illustration of the close relationship of climatic factors, plant growth, and composition. In 1937 all three types of samples show a downward trend in protein content as the season advances. There is a similar trend in dry matter yields.

There was no correlation between precipitation and protein content using "A", "B", and "C" samples. However, there was a significant correlation between dry matter yields of the "B" samples and precipitation. No correlation was found between precipitation and dry matter yields of "A" samples.

BROME GRASS

Brome grass (*Bromus inermis*) has yielded more dry matter of uniformly high nutritive value than other grass crops used in these comparisons. Table 4 shows the seasonal and the period yields of brome

TABLE 4.—*Brome grass yields of oven-dry matter per acre for 1935, 1936, and 1937 by "A" and "B" methods of calculation.*

1935			1936			1937		
Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre	
	"A"	"B"		"A"	"B"		"A"	"B"
May 3	2,341	2,341	May 1	1,252	1,252	May 4	1,194	1,194
May 24	2,473	1,423	May 26	1,579	1,579	June 8	3,548	2,687
June 21	4,099	1,700	June 26	1,834	257	July 1	1,132	693
July 19	1,330	1,839	July 21	− 936	0	July 29	2,012	1,524
Aug. 30	649	2,006	Aug. 25	613	1,076	Aug. 16	− 121	490
Sept. 27	− 252	850	Sept. 15	289	625	Oct. 30	− 486	752
						Nov. 17	− 514	126
Total seasonal yield	10,640	10,159		4,631	4,789		6,765	7,466

grass for the years 1935, 1936, and 1937. Total yields of brome grass more nearly reflected the effect of season than did those of Reed canary grass. Total seasonal yield in 1935 by the "A" method was 10,640 pounds of dry matter and the "B" method 10,159 pounds. This is a comparatively close agreement. In 1936 the yields were 4,631 and 4,789 pounds of dry matter, respectively, for the "A" and "B" methods, again a very close agreement, and in 1937 the yields of dry matter were 6,765 and 7,466 pounds, respectively, for the "A" and "B" methods. Referring to the period yields for each year it will be seen that the "A" yields are usually much higher during the forepart of the growing season when photosynthetic activity is greatest and when the system of cutting which disturbs this process the least is the most conducive to rapid growth. Variations are smaller and yields from the later part of the season more nearly reflect the conditions found on a well-grazed pasture.

Results of chemical analyses of smooth brome grass are shown in Tables 5, 6, and 7. As in Reed canary grass, the seasonal trends in 1935 (Table 5) were marked by some variation; however, there was

TABLE 5.—*Brome grass the 1935 protein, calcium, and phosphorus content of the "A", "B", and "C" forage samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 24......	13.58	18.22	15.81	0.392	0.481	0.455	0.272	0.366	0.316
June 21......	10.28	15.18	9.41	0.339	0.437	0.312	0.212	0.345	0.205
July 19......	12.31	16.06	10.46	0.370	0.459	0.375	0.227	0.302	0.209
Aug. 30......	13.07	18.44	10.02	0.476	0.570	0.436	0.241	0.319	0.194
Sept. 23......	15.59	16.49	11.09	0.553	0.560	0.424	0.202	0.126	0.143

a tendency for the percentage protein content of the "A", "B", and "C" samples each to form a hyperbolic curve. The protein content of the "A" and "C" samples was approximately the same, but that of the "B" samples was considerably higher. Differences in percentages of calcium and phosphorus followed a trend similar to that of the protein. In 1936 the very marked effect of seasonal distribution of rainfall is seen (Table 6) on protein content during the later part of the season. A sharp increase in protein and minerals is noted in "A",

TABLE 6.—*Brome grass the 1936 percentage content of protein, calcium, and phosphorus of the "A", "B", and "C" forage samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
June 26......	8.95	15.10	8.37	0.357	0.497	0.357	0.158	0.245	0.170
July 21......	7.16	—	5.86	0.396	—	0.366	0.122	—	0.106
Aug. 24......	10.12	20.85	9.99	0.375	0.508	0.329	0.178	0.305	0.145
Sept. 15......	19.26	25.68	20.26	0.463	0.520	0.428	0.269	0.337	0.249

"B", and "C" samples. The 1937 analyses are comparable to the results obtained in 1935. With a single exception the protein, calcium, and phosphorus contents were uniformly distributed throughout the season (Table 7). The "B" samples were again uniformly high in protein.

TABLE 7.—*Brome grass the 1937 protein, calcium, and phosphorus content of the "A", "B", and "C" forage samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 4	——	22.88	——	——	——	——	——	0.385	——
June 8	11.19	12.80	8.63	0.288	0.306	0.233	0.265	0.307	0.259
July 1	7.76	16.81	8.00	0.236	0.338	0.271	0.268	0.388	0.184
July 29	11.69	17.79	8.20	0.351	0.410	0.300	0.193	0.286	0.159
Aug. 16	14.19	22.62	8.44	0.326	0.427	0.353	0.211	0.322	0.168
Oct. 30	15.06	19.63	13.84	0.439	0.549	0.485	0.200	0.291	0.196
Nov. 17	11.48	13.76	8.62	0.466	0.422	0.387	0.170	0.208	0.146

KENTUCKY BLUEGRASS

Yields of bluegrass at Urbana, Ill., have, with the exception of 1935, been invariably smaller than those obtained from brome grass, Reed canary grass, or orchard grass. Periods of high dry-matter production by Kentucky bluegrass usually occur early in the season with a second high in the months of September and October. Precipitation and temperature are apparently closely related to these high production peaks. Mid-summer productivity has usually been low. Maturity usually occurs during May and early June, but during favorable growing seasons, such as 1935, maturity is delayed as contrasted with the season of 1936. In 1935 the grass attained greater heights before heading and leaf growth was more abundant. This is indicated in Table 8 which shows that early period productivity was greater in 1936 than in 1935. Early heading with the attendant stemminess gave larger initial sampling period weights.

Total seasonal production by the "A" method in 1935 was 6,001 pounds of dry matter; by the "B" method 5,304 pounds, a difference of 697 pounds. In 1936, a total of 3,159 pounds of dry matter was harvested by the "A" method and 4,257 pounds by the "B" method, a difference of 1,098 pounds, reversing the increase in 1935 by the "A" method. In 1937, 4,815 pounds of dry matter were produced using the "A" method and 4,078 pounds by the "B" method, a difference of 737 pounds.

As stated previously yields of Kentucky bluegrass usually were smaller than those of brome grass and Reed canary grass, but the protein and mineral composition were somewhat higher. From this it would seem that a smaller yield of bluegrass would more than equal a larger yield of brome grass, but the yield of brome grass was sufficiently larger to offset the differences in composition. Another factor militating against bluegrass is its increased toughness as the summer

TABLE 8.—*Kentucky bluegrass yields of oven-dry matter per acre for 1935, 1936, and 1937 by "A" and "B" methods of calculation.*

1935			1936			1937		
Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre	
	"A"	"B"		"A"	"B"		"A"	"B"
Apr. 26	699	699	Apr. 24	1,408	1,408	May 4	794	794
May 24	1,219	1,413	May 22	747	1,661	June 1	1,971	989
June 21	1,665	1,097	June 19	506	465	July 20	1,030	1,279
July 19	874	1,097	July 1	− 149	0	Sept. 4	1,277	632
Aug. 13	524	494	Aug. 29	487	442	Nov. 15	− 257	384
Sept. 11	1,020	504	Sept. 26	160	281			
Total seasonal yield	6,001	5,304		3,159	4,257		4,815	4,078

advances. This may be associated with the presence of seed stems and partial dormancy during some seasons. It is a matter of common observation that neither sheep nor cattle seem to relish the seed stems, and that bluegrass during this stage of its development does not produce a great abundance of leaves, while brome grass grows sufficiently tall and leafy to provide good grazing.

Tables 9, 10, and 11 show the chemical composition of Kentucky bluegrass for 1935, 1936, and 1937. It should be noted that the bluegrass pasture referred to in this paper was high in fertility which accounts largely for the high yields.

TABLE 9.—*Kentucky bluegrass the 1935 protein, calcium and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 24......	17.91	19.67	16.77	0.348	0.458	0.294	0.334	0.397	0.323
June 21......	14.07	16.66	12.60	0.397	0.370	0.295	0.277	0.178	0.267
July 19......	14.23	18.24	13.84	0.260	0.255	0.234	0.234	0.271	0.182
Aug. 13......	14.04	18.59	13.97	0.316	0.381	0.361	0.136	0.255	0.211
Sept. 10......	15.63	18.96	13.87	0.343	0.337	0.300	0.218	0.209	0.210

The term "high fertility" may need some clarification. There are seven or more 10-acre bluegrass pastures on the Animal Husbandry Farm, most of them located on highly fertile soil, but one or two are on soil comparatively low in fertility and consequently relatively low in productivity.

The protein, calcium, and phosphorus content of Kentucky bluegrass shows a protein content equal to, or exceeding, that of brome grass. Calcium and phosphorus, although variable, were approxi-

TABLE 10.—*Kentucky bluegrass the 1936 protein, calcium and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 22......	12.45	12.68	13.22	0.302	0.241	0.272	0.289	0.274	0.287
June 19......	8.53	12.73	8.10	0.199	0.291	0.218	0.139	0.221	0.123
Aug. 1.......	7.53	—	6.98	0.222	—	0.242	0.115	—	0.102
Aug. 29......	12.54	17.72	12.85	0.284	0.351	0.273	0.158	0.212	0.153
Sept. 26......	22.06	24.41	18.66	0.391	0.484	0.404	0.277	0.260	0.245

TABLE 11.—*Kentucky bluegrass the 1937 protein, calcium and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 4.......	—	22.56	—	—	—	—	—	0.441	—
June 1.......	12.10	13.14	10.65	1.830	0.206	1.975	0.276	0.282	0.251
July 20......	—	9.87	13.12	—	0.366	0.250	—	0.280	0.198
Sept. 5.......	10.99	11.68	8.68	0.338	0.417	0.255	0.176	0.375	0.158
Nov. 15......	17.61	19.71	—*	0.439	0.510	—*	0.265	0.269	—*

*Insufficient growth for a sample.

mately the same. However, on the basis of yields, total protein and mineral content of Kentucky bluegrass is less than that of brome grass. It is also interesting to note the very large and rapid rise in protein content of Kentucky bluegrass in the late part of the growing season.

In 1935 the seasonal changes in protein content on all samples were small and the low point differed from the high point by approximately 3.5%. The calcium and phosphorus content in 1935, 1936, and 1937 followed similar trends.

The effect of season on composition is very apparent and is more clearly defined when a comparison is made between the composition tables of bluegrass for 1935 and 1936. "B" samples for September 1 are lacking for want of enough growth to provide a sample. It is again emphasized that all samples are composites and no attempt was made to select green material for a sample. From a practical point of view the "A" samples would seem to be more nearly equal to the actual forage consumed by the animal. Chemical composition data are not complete for 1937, but have nevertheless been included for comparative purposes in Table 8. This field was grazed very closely so that on November 15, the final sampling date, insufficient material remained for "C" samples. This is a late date for pasturing in central Illinois, but temperature and moisture conditions were good so the livestock were kept on the pasture.

Kentucky bluegrass still remains as one of the most persistent, aggressive, productive, and economical pasture grasses, when its

relatively high nutritive value based on composition is considered, as well as its apparent palatability.

ORCHARD GRASS

The productivity and chemical composition of orchard grass (*Dactylis glomerata*) usually falls between that of Reed canary grass and Kentucky bluegrass, although considerable variation is found depending upon seasonal effects.

Orchard grass produces well, with the peak of its productivity coming early in the season, and it is during this period that it is consumed most readily by livestock. It has been frequently observed on the orchard grass pastures that when it is in the seed stem stage, cattle and sheep consume less, due to its coarse tough character. It has a second peak in productivity and apparently increased palatability in the late fall, evidently the result of improved moisture conditions and decreased temperatures.

Total seasonal yield in 1935 by the "A" method was 5,906 pounds, by the "B" method 5,533 pounds, a difference of 363 pounds of dry matter in favor of the "A" method (Table 12). In 1936 yields of dry forage by the "A" and "B" methods were, respectively, 4,189 and 3,539 pounds, a difference of 650 pounds favoring the "A" method. Residual growth or the "C" forage remaining on the pasture in 1935

TABLE 12.—*Orchard grass yields of oven-dry matter per acre for 1935, 1936, and 1937 by the "A" and "B" methods of calculation.*

1935			1936			1937		
Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre		Cutting dates	Period yields dry matter, lbs. per acre	
	"A"	"B"		"A"	"B"		"A"	"B"
Apr. 26	799	799	May 27	1,752	1,752	May 4	1,236	1,236
May 24	1,711	1,641	June 26	1,006	504	June 7	3,649	1,109
June 12	——	949	July 21	-92	0	July 1	426	427
July 19	1,675	1,117	Aug. 24	728	529	July 29	1,078	773
July 26	1,008	217	Sept. 15	111	235	Aug. 16	103	190
Aug. 17	100	100	Nov. 11	684	519	Sept. 15	733	183
Aug. 23	236	236				Oct. 23	-818	416
Oct. 15	377	475						
Total seasonal yield	5,906	5,533		4,189	3,539		6,407	4,334

was 917 pounds, in 1936 only 60 pounds, an indication of the effect of season on productivity and consumption. In 1937, the "A" yield of dry forage was 6,407 pounds, the "B" yield 4,334 pounds, a difference of 2,073 pounds. This difference appeared on the second sampling date and was the result of overgrazing during the previous very dry, hot season of 1936. The "B" samples, it will be recalled, are those obtained from a previously clipped, protected area and each sample

represents the growth accruing in the interim. Close clipping necessitates the use of reserves for new top growth.[5] Lacking reserves due to previous depletion would reduce the productivity to a marked degree.

Chemical composition of orchard grass follows the same general pattern of the other grasses. A curve drawn to represent the seasonal trend in composition is usually in the form of a hyperbola and falls between that of brome grass and Reed canary grass, although here again there are seasonal variations. A point of interest is the relatively high and uniform calcium content of orchard grass compared with either brome grass or bluegrass. The phosphorus content is low, although considerable variation occurs with respect to the year. Tables 13, 14, and 15 present the protein, calcium, and phosphorus content of orchard grass.

Composition of orchard grass has varied more from year to year than have the other grasses, particularly in the case of the protein content. The very small protein percentages in the case of "A", "B", and "C" samples for 1937 are interesting, but again are explainable on the basis of depleted food reserves as a result of the excessive hot, dry season of 1936.

TABLE 13.—*Orchard grass the 1935 protein, calcium, and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 24	12.55	13.19	11.52	0.343	0.319	0.309	0.292	0.338	0.346
June 11*	——	14.84	9.10	——	0.400	0.334	——	0.455	0.282
July 26	11.12	13.49	8.49	0.381	0.438	0.402	0.335	0.421	0.165
Oct. 15	11.93	14.51	10.42	0.449	0.497	0.455	0.196	0.177	0.232

*No "A" sample obtained for chemical analyses.

TABLE 14.—*Orchard grass the 1936 protein, calcium, and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
June 26	7.94	15.88	6.00	0.376	0.532	0.323	0.192	0.298	0.211
July 21	5.34	——	6.37	0.333	——	0.247	0.176	——	0.146
Aug. 24	11.46	17.78	6.31	0.364	0.493	0.323	0.171	0.261	0.143
Sept. 15	18.89	22.09	22.62	0.540	0.523	0.483	0.298	0.293	0.298
Nov. 11	23.88	29.92	25.22	0.468	0.478	0.510	0.386	0.422	0.391

Some observations on orchard grass indicate that it lacks apparent palatability. On the basis of chemical analyses the answer cannot be

[5]GRABER, L. F. Food reserves in relation to other factors limiting the growth of grasses. Plant Physiology, 6:43–72. 1931.

TABLE 15.—*Orchard grass the 1936 protein, calcium, and phosphorus content of the "A", "B", and "C" samples.*

Sampling dates	Protein, %			Calcium, %			Phosphorus, %		
	"A"	"B"	"C"	"A"	"B"	"C"	"A"	"B"	"C"
May 5	—	18.19	—	—	—	—	—	0.386	—
June 7	6.25	8.63	6.68	0.214	0.181	0.180	0.255	0.405	0.276
July 1	5.31	14.48	3.75	0.188	0.289	0.177	0.217	0.346	0.235
July 29	7.38	12.14	6.37	0.242	0.387	0.270	0.221	0.398	0.192
Aug. 16	8.68	14.19	7.63	0.286	0.370	0.307	0.207	0.318	0.208
Sept. 15	8.58	14.29	6.87	0.333	0.421	0.309	0.169	0.269	0.135
Oct. 23	11.73	16.59	9.25	0.361	0.342	0.321	0.221	—	0.182

found in its protein content alone, although from the 1937 analyses some cognizance must be given this point. It may be partly due to the quality of the proteins or the low phosphorus content. Another factor not presented here, namely, the crude fiber content, indicates that orchard grass and Reed canary grass contain a larger percentage of fiber than do brome grass or Kentucky bluegrass. This perhaps militates against the apparent palatability of orchard grass to livestock; however, orchard grass seldom is used in pure stands as a pasture but is more often included in pasture mixtures used in central and southern Illinois. Animal gains on orchard grass, brome grass, Reed canary grass, and Kentucky bluegrass will be discussed in a subsequent paper and will serve to clarify the picture of palatability based on consumption and animal preference.

No attempt is made to draw conclusions from the data obtained on these pastures at the present time. The experiments are being continued and the results will be presented at a future date. The material presented in this paper indicates certain definite trends and relationships and these trends and relationships become more clearly defined as the volume of data increases.

SUMMARY

Data are presented showing the yields of oven-dry forage from Reed canary grass, brome grass, Kentucky bluegrass, and orchard grass pastures at Urbana, Illinois. Chemical analyses of "A", "B", "C" forage samples are tabulated and indicate the protein, calcium, and phosphorus content of the above grasses. Comparisons of the yield and composition show that brome grass has yielded more oven-dry forage per acre than the other grasses discussed. In terms of total digestible nutrients produced per acre brome grass has also outyielded these other grasses, but on the basis of percentage composition Kentucky bluegrass usually contains more digestible nutrients per pound than brome grass, Reed canary grass, or orchard grass.

Considerable variability in composition was found in the same species in different seasons. This was apparently a seasonal effect due in part to previous management, to type of livestock used, or to the physiological effects of environment, more specifically precipitation

and temperature. The data on the chemical composition of the forage grasses discussed in this paper are in the form of hyperbolic curves, the reverse of the seasonal temperature curves which were in the form of parabolas.

Yields as calculated by the "A" and "B" methods usually vary from each other depending on season and previous treatment of the pasture. Following the season of 1936 forage yields of a bunch-type grass, such as orchard grass, showed larger differences between "A" and "B" yields than did the sod-forming bluegrass and brome grass.

THE CHEMICAL COMPOSITION OF PASTURE SPECIES OF THE NORTHEAST REGION AS INFLUENCED BY FERTILIZERS[1]

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THE literature on this subject was well reviewed and discussed in several papers presented at a symposium on pastures before a joint session of the Northeastern Section of this Society and Section O of the American Association for the Advancement of Science at Atlantic City, New Jersey, December 29, 1936. Those papers were published in this JOURNAL (Vol. 29:441–511, 1937). Because of that rather recent and exhaustive review, no literature is cited here.

The purpose now is to present in brief form some of the pasturage analyses made since 1931.[3] No attempts will be made to interpret these data in terms of animal nutrition. Such interpretations must await the results of carefully conducted feeding trials, of which there have been very few involving pasturage. In the opinion of the writer, there is a great need for experiments to determine the effects of different kinds of forage on various classes of livestock. However, judging from the growth records of hundreds of dairy heifers which have grazed our experimental pastures for many seasons, animals do not reflect rather wide variations in certain chemical constituents of pasturage, provided there is a sufficient quantity of it. This does not mean that the efficiency values of a given amount of *dry matter* from even slightly different kinds of pasturage may not vary markedly.

PERMANENT PASTURES[4]

Over 300 samples of freshly grown herbage, approximately 4 inches high, were collected during the 5 years, 1932 to 1936. They represent 17 2-acre plots on which production was measured by rotational grazing with dairy heifers. The soil is Charlton fine sandy loam, naturally acid (pH 5.2), and very deficient in easily soluble phosphorus.

The important species in the samples were the four that occur naturally in this region, as follows: (1) Kentucky bluegrass (*Poa pratensis*), which varied from 1% on the unfertilized plot to 50% on the mineral (PL or PLK) pastures and to 75% under mineral plus N treatments; (2) Rhode Island bent grass (*Agrostis tenuis*), a species that maintains a much more uniform stand than bluegrass under the varied conditions; (3) wild oat or "poverty" grass (*Danthonia spicata*), which occurred only on the non-phosphated plots; and (4) white clover (*Trifolium repens*). During the period under consideration,

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[4]The treatments under test and an explanation of symbols may be found in Table 1.

this legume occupied only from 10 to 15% of the area in the PL or PLK pastures, except the one which received the first P in 1932, where clover reached a peak of 70% in 1933. The no P and mineral plus N plots had small amounts (5% or less) of clover. Because of its low habit of growth, the samples contained less clover than indicated by the percentages of occupied area.

Besides these four, small amounts of sweet vernal grass (*Anthoxanthum odoratum*) occurred in all of the pastures. In general, most of the samples from all plots receiving P consisted of blue and bent grasses; from the non-phosphated plots, of bent and poverty grass. Each sample was analyzed for ash, protein, fiber, N-free extract, ether extract, P, K, and Ca. The season's samples from a few plots were composited and analyzed for Si, Fe, Al, Mn, S, Cl, and Mg.

To save space, only the 5-year averages are given here. However, it may be stated that the variations between annual averages for any given plot were not greater than the intra-seasonal differences, a point to be discussed later. The "feed" and major mineral constituent analyses, shown in Table 1, indicate a generally high feeding value for the pasturage of all plots, except those without fertilizer P. The latter group produced herbage containing only about 75% as much protein and 60% as much P, but considerably more fiber and N-free

TABLE 1.—*Chemical composition of pasturage from grazed plots as affected by fertilization, averages of all analyses for 5 years, 1932–36.*

Fertilization*	Plots in group	Dry matter %	Analyses as percentage of dry matter								Ca:P Ratio
			Ash	Protein	Fiber	N-free extract	Fat	P	K	Ca	
No P†	3E, 5	30.8	8.0	18.1	23.4	46.9	3.62	0.21	2.13	0.61	2.9
P and PK	2E, 2W, 7E	26.3	8.0	22.7	21.7	43.8	3.91	0.32	2.43	0.66	2.0
PL and PLK	1N, 1S, 8N	26.1	8.3	24.3	21.1	42.4	4.05	0.34	2.45	0.69	2.0
PLK‡	3W	25.1	8.3	24.0	21.1	42.7	3.95	0.35	2.31	1.01	2.9
PLK§	8S	26.5	8.4	23.1	21.4	43.2	3.99	0.28	2.49	0.65	2.3
PKN1	9N	24.3	8.1	26.1	21.5	40.2	4.12	0.35	2.71	0.55	1.6
PKN2	9S	24.4	8.2	24.6	21.6	41.5	4.04	0.34	2.41	0.56	1.6
PKN3	7W	24.8	8.3	24.5	21.6	41.8	3.89	0.34	2.59	0.57	1.7
PLKNN1	6N	26.0	8.1	27.5	20.9	39.3	4.24	0.33	2.69	0.57	1.7
PLKN12	6S	25.3	7.9	26.4	21.1	40.4	4.18	0.33	2.59	0.56	1.7
PLKN23	4S	24.7	7.8	26.1	21.4	40.4	4.21	0.36	2.62	0.52	1.4
PLKN123	4N	24.9	7.9	26.9	21.2	39.8	4.26	0.37	2.62	0.52	1.4
All N plots	—	24.9	8.1	26.0	21.3	40.5	4.13	0.35	2.60	0.55	1.6

*P = Superphosphate (16%) to supply a total of 320 pounds of P_2O_5 per acre from 1924 to 1935.
K = Muriate of potash to supply a total of 200 pounds of K_2O per acre from 1924 to 1935.
L = Limestone, a total of 2 tons per acre from 1924 to 1932.
N = Nitrogen at 28 pounds per acre annually.
NN = Nitrogen at 56 pounds per acre annually.
On most of the plots the *total* amounts of superphosphate and potash were divided equally between 1924, 1929, 1932, and 1935 applications; the limestone equally between 1924 and 1926 additions. The nitrogen was supplied by a 2:1 sulfate of ammonia-nitrate of soda mixture through 1934 and by Calnitro thereafter.
The numbers following the letters "N" or "NN" refer to time of applying the nitrogen: 1 means April; 2, June; and 3, August applications.
†The No-P group includes the unfertilized and LK plots.
‡First P applied in 1932.
§No P since 1924.

extract. Superphosphate alone caused the greatest improvement of any single fertilizer. This might be expected because of the extremely P-deficient state of most pasture soils in the Northeast. Adding limestone with the superphosphate further increased the desirable chemical characteristics of the pasturage. The influence of large proportions of clover on the Ca content is evident for plot 3W, where superphosphate was applied for the first time in 1932. Also, the somewhat lower percentage of protein plus the distinctly reduced P content may be noted for 8S, where no superphosphate has been added since the original treatment of 500 pounds per acre in 1924. Nevertheless, in 1938, or 14 years after the *first* and *last* application of P on 8S, the vegetation there contained about 40% more P than that from the unfertilized plot.

The several pastures receiving N, in addition to minerals, produced forage slightly richer in N and P but appreciably lower in Ca. This reduction in Ca is thought to be due partly to less clover and partly to the greater prevalence of bluegrass, which (as will be shown later) contains less Ca than bent grass, the other most dominant species on these pastures.

The Ca:P ratios vary from 1.4 for the high N plots to 2.9 for the no P and the recently phosphated pastures. The relatively high ratio of the no P group is due to the very low amount of P, while in the case of the recently phosphated plot, it traces to the larger amount of Ca in white clover which prevailed there during the period under discussion.

It is interesting to note that the P values fall for the most part between 0.32 and 0.37% or slightly above what has been termed the "critical point" for Kentucky bluegrass. ("Critical point" is the lowest nutritional level at which a species will produce optimum yields.) However, these P values are appreciably below those published for bluegrass grown in Kentucky. That these differences are due to the level of readily available P in the soil is indicated by the annual P analyses of the vegetation from a few plots (Table 2). It is readily apparent that in the years when superphosphate was applied, the P contents of the pasturage rose appreciably, over 20% in one case. There is also a noticeable trend upward with each succeeding P treatment.

TABLE 2.—*Phosphorus in pasturage.*

Fertilization*	P in dry matter, %				
	1932†	1933	1935†	1936	1938†
P	—	0.31	0.37	0.33	0.39
⅓ P annually	—	0.32	0.32	0.32	0.32
PL	0.37	0.33	0.39	0.34	0.39
PLK	0.39	0.34	0.38	0.34	0.43
PLK (P in 1924 only)	0.32	0.28	0.30	0.28	0.28
PLKNN1 and N12	0.35	0.30	0.40	0.32	0.41

*See Table 1 for explanation of symbols.
†Years when superphosphate was applied to all plots unless otherwise noted.

Applying one-third of the superphosphate each year resulted in a very uniform *annual* P content of the herbage. Probably there is no practical advantage in obtaining such *annual* uniformity, for a change in age or in weather conditions has caused greater intra-seasonal differences in the P contents of pasture plants.

The Si, Fe, Al, Cl, S, Mn, and Mg analyses for six differently fertilized pastures are given in Table 3. The outstanding features of

TABLE 3.—*Some other elements in pasturage, averages for 1932–36.*

Fertilization*	Analyses as % of dry matter						
	Si	Fe	Al	Cl	S	Mn	Mg
None	1.64	0.040	0.037	0.75	0.27	0.033	0.19
P	0.84	0.021	0.019	0.68	0.28	0.034	0.22
PK	0.69	0.016	0.012	0.85	0.29	0.033	0.23
PL	0.86	0.023	0.024	0.79	0.30	0.019	0.23
PLK	0.82	0.021	0.024	0.72	0.30	0.021	0.24
PLKNN1	0.59	0.019	0.016	0.87	0.33	0.020	0.22

*See Table 1 for explanation of symbols.

these data are the relatively high amounts of Si, Fe, and Al in the unfertilized vegetation, their values being nearly double those for the other plots. The percentages of S and Mg in the herbage from the untreated pasture are slightly below those from any of the others.

Among the five fertilized plots represented in this study, there appears to be no consistent influences of K, L, or N on the percentages of Si, Fe, Al, Cl, or Mg. S is somewhat higher in the herbage that received N and in turn the PL and PLK pasturage is slightly above that from the P or PK plots.

Mn exhibits the most consistent differences, the values for the three unlimed plots each being about 60% above those for the three limed ones. It has long been known that the availability of Mn to plants is greatly reduced by liming the soil. In this case, the reaction of the upper 3 inches of soil from the limed pastures was pH 5.73 or only 0.46 pH above the unlimed soil. The lower layers of soil from the two groups had even smaller differences in reactions.

INTRA-SEASONAL VARIATIONS

For this study, the samples of 1931 are included with those of 1932 to 1936, making a total of 356. These are divided into six groups according to the season when they were collected. Four of the groups correspond exactly to calendar months, but the first period extends only to May 20, while the second does not end until June 30. These irregular periods were adopted to avoid having any flowering or headed grasses in the first period and to cover in the second the entire time of normal flower and seed development. Even when kept grazed to a very few inches in height, grasses will develop some stems and heads which have considerable influence on the chemical composition.

The averages, given in Table 4, have the following conspicuous features: (1) Total ash is very high in October; (2) protein is highest in early May and lowest in October; (3) fiber is lowest in early May and highest in late May and June; (4) fat is much higher in early May than in any of the other periods, June and October having somewhat lower values; (5) the P peak is reached in early May, the low point in July, the low July value probably being due to less moisture in the soil as lack of moisture generally has an unfavorable effect on the amount of that element in pasturage; and (6) Ca is lowest in early May and highest in July or just the reverse of P, a common observation, the causes, however, having not yet been determined.

TABLE 4.—*Intra-seasonal differences in the chemical composition of pasturage, averages of 1931–36.*

Period when sampled	No. of samples	Dry matter, %	Analyses as % of dry matter								Ca:P ratio
			Ash	Protein	Fiber	N-free extract	Fat	P	K	Ca	
Before May 20......	77	26.2	7.4	26.9	19.4	41.8	4.50	0.35	2.56	0.57	1.6
May 20–June 30..	88	25.9	7.6	23.2	23.2	42.3	3.70	0.30	2.38	0.64	2.1
July.......	61	27.8	8.0	22.2	23.1	42.8	3.91	0.29	2.31	0.68	2.3
August....	47	25.7	8.2	24.0	21.8	42.0	3.99	0.32	2.41	0.65	2.0
September.	69	25.8	9.0	24.5	20.7	41.9	3.96	0.33	2.56	0.67	2.0
October...	14	30.4	10.5	20.3	20.4	45.2	3.68	0.31	2.27	0.61	2.0
Total or average	356	27.0	8.4	23.5	21.4	42.7	3.96	0.32	2.42	0.64	2.0

These intra-seasonal fluctuations have been calculated as percentages of the averages of the respective plots for each season. Frequently such values exceeded 25% and in a few cases reached 40% of the annual means. Ash, protein, and Ca are the constituents which have varied by 40% or more. These facts indicate how difficult it will be to obtain, for any length of time, *fresh* forage of uniform chemical characteristics for experiments to determine the exact feeding values of pasturage.

SEEDED PLOTS

In Table 5 are tabulated the N, P, K, and Ca analyses for timothy seeded with red clover in 1931 and mowed June 1 in each of the 5 years, 1933 to 1937. The entire field had the same mineral (PLK) treatments, but the N varied from 0 to 28 and to 56 pounds per acre. The N was furnished in the form of a 2:1 sulfate of ammonia-nitrate of soda mixture in 1933 and 1934 and as Calnitro in the last 3 years.

Superphosphate (16%) at 500 pounds and muriate of potash (50%) at 200 pounds were added in 1936, the first P or K applied since 1930. These fertilizers had an appreciable effect in raising the P and K in the timothy in 1936 and to some extent in 1937. Although

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TABLE 5.—*Timothy, mowed June 1, as affected by fertilization, average of duplicate plots.**

Nitrogen, lbs. per acre annually	Analyses as % of dry matter					
	1933	1934	1935	1936	1937	Average
			Nitrogen			
None	2.09	1.95	1.63	2.12	2.05	1.97
28	2.08	2.03	1.82	1.95	2.04	1.98
56	2.22	2.30	2.08	2.22	2.13	2.19
			Phosphorus			
None	0.28	0.26	0.24	0.31	0.29	0.28
28	0.30	0.24	0.22	0.36	0.28	0.28
56	0.28	0.25	0.22	0.30	0.27	0.26
			Potassium			
None	1.85	1.70	1.53	2.26	2.13	1.89
28	1.86	1.68	1.25	2.31	1.67	1.75
56	1.62	1.35	1.10	2.32	1.27	1.53
			Calcium			
None	0.73	0.69	0.55	0.59	0.59	0.63
28	0.67	0.67	0.66	0.55	0.60	0.63
56	0.64	0.72	0.65	0.57	0.60	0.64

*N applied annually in April and supplied by 2 parts sulfate of ammonia and 1 part nitrate of soda in 1933–34; by Calnitro in 1935–37. P_2O_5 at 80 pounds and K_2O at 100 pounds in 1936.

the timothy was 12 to 15 inches high and much older than the 4-inch bluegrass from the permanent pastures, their P contents in 1936 were practically the same.

Nitrogenous fertilizers have been widely recommended for the purpose of increasing the N or protein content of grass hay. In that respect, even this very early cut timothy was not increased at all by 28 pounds of N and by only about 10% by the 56 pounds of N. Other data from this experiment show that early cutting is much more influential than nitrogenous fertilizers.

Excepting 1936, the K values are much lower for the timothy receiving the heavier amount (56 pounds) of N. This indicates a lack of proper balance in the supply of those nutrients.

In another experiment, Kentucky bluegrass and Rhode Island bent grasses were seeded in pure cultures in August, 1935, on soil with a pH of 5.3 and well supplied with P and K. In 1936 and succeeding years, triplicated 25 by 6 foot plots of each grass were treated with sufficient amounts of several nitrogenous fertilizers to furnish 84 pounds of N per acre, divided into April, June, and August applications. The grasses were cut when 3½ inches to 1 inch with a motor lawnmower, the clippings removed, weighed, and sampled.

In 1938, the third year of the experiment, the samples were analyzed for N, P, K, Ca, and Mg. The effects of the different N carriers on the N, P, and Ca contents of the grasses are shown graphically in Figs. 1, 2, and 3 and on the percentages of K and Mg in Table 6.

TABLE 6.—*Effects of sources of N on the Mg and K contents of grasses.*

Source of N	% in dry matter			
	Kentucky bluegrass		Rhode Island bent grass	
	Mg	K	Mg	K
$NaNO_3$	0.28	1.28	0.28	1.59
$(NH_4)_2SO_4$	0.27	1.12	0.27	1.70
$Ca(NO_3)_2$	0.30	1.21	0.30	1.25
Urea	0.28	1.23	0.30	1.43
Urea + Na_2SO_4	0.26	1.59	0.25	1.80
Calnitro (84 lbs. N)	0.39	0.98	0.31	1.51
Calnitro (168 lbs. N)	0.46	0.81	0.42	1.25

From the graphs, it is readily apparent that on this acid soil the use of the physiologically acid salts, $(NH_4)_2SO_4$ and especially NH_4Cl, resulted in lower N, P, and Ca contents in both grasses. In respect to N, $(NH_4)_2CO_3$ was equally as poor as NH_4Cl but it did not depress the Ca and P. Urea had much more favorable effects than the ammoniates especially in regard to the percentages of Ca and P. Adding NA_2CO_3 at 330 pounds or Na_2SO_4 at 495 pounds per acre, with urea, apparently had little effect on the N contents of either grass, depressed the Ca in both species, and gave contradictory results for P.

Among the physiologically alkaline carriers, cyanamid was somewhat inferior, judging from the N and P contents of the grasses. However, cyanamid and $Ca(NO_3)_2$ were responsible for the highest values for Ca. In this experiment, $NaNO_3$ is the third Na salt to reduce Ca in the grasses, indicating a retarding effect of Na on the availability or absorption of Ca.

Calnitro, a neutral carrier, has high values for N, but is slightly inferior to cyanamid when the analyses for Ca and P are considered. It is very noticeable that this fertilizer, which contains dolomitic limestone, increased the Mg and decreased the K contents of the grasses. (See Table 6.) Na_2SO_4 had just the opposite effects. In the case of bent grass, $(NH_4)_2SO_4$ appears to have increased the K, but this is not true of bluegrass. The K values are quite high for the grass samples from the $NaNO_3$ plots, probably due to replacement of K by Na in the soil exchange complex. This explanation would apply also to the other Na compounds.

In general, these data illustrate what marked changes in the mineral contents of grasses may be caused by using different sources of N or adding other chemicals not commonly used as fertilizers. Although grazing animals may thrive on pasturage of widely varying mineral contents, it seems probable that the chemical composition of a species could be changed to a point where its nutritive value might be either seriously reduced or greatly improved. When one considers that each of the many elements in grasses may occur in greatly different proportions, determining the feeding values of pastures appears to be a very complicated problem.

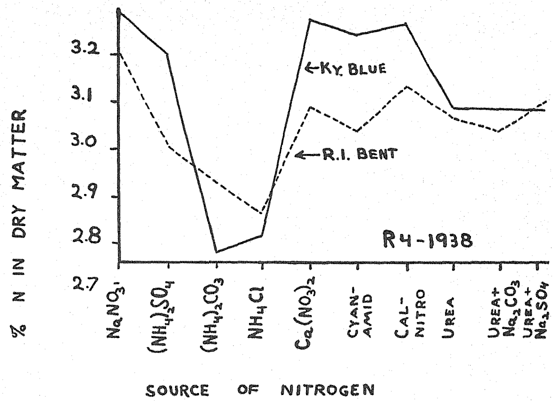

FIG. 1.—Effects of source of N on the N contents of Kentucky bluegrass (*Poa pratensis*) and Rhode Island bent grass (*Agrostis tenuis*).

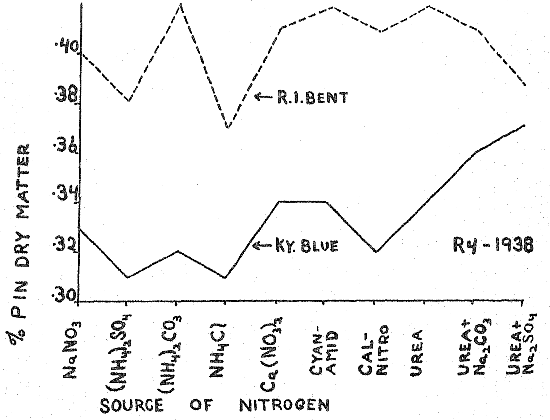

FIG. 2.—Effects of source of N on the P contents of Kentucky bluegrass (*Poa pratensis*) and Rhode Island bent grass (*Agrostis tenuis*).

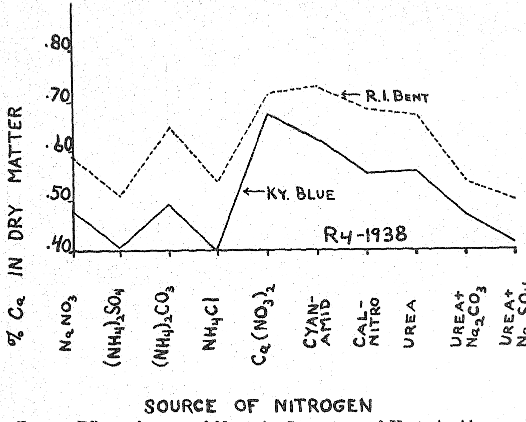

FIG. 3.—Effects of source of N on the Ca contents of Kentucky bluegrass (*Poa pratensis*) and Rhode Island bent grass (*Agrostis tenuis*).

SUMMARY

Chemical analyses of over 300 samples of pasturage from 17 variously fertilized permanent, grazed plots were made from 1932 to 1936. The fertilizers ranged from superphosphate alone to complete minerals (PLK) plus 84 pounds of N per acre annually.

Superphosphate caused the greatest improvement in important nutritional characteristics, namely, a 25% increase in protein, a 5% decrease in fiber, and a 50% increase in P. In these respects, further advances were due to adding limestone and, or, nitrogenous fertilizers with superphosphate.

Superphosphate (16%) at 500 pounds per acre in 1924 was responsible for a 40% increase in the P in the pasturage in 1938. This emphasizes the importance of conducting pasture experiments over long periods.

The Ca:P ratios varied from 1.4 for the PLK plus high N plots to 2.9 for the non-phosphated pastures.

The Si, Fe, and Al contents of the unfertilized vegetation were each approximately double those found in the P or P+ pasturage. Mn was consistently 60% higher in the grasses from the unlimed plots. S, Cl, and Mg did not vary so much as the elements just mentioned and the effects of fertilization were much less evident.

Intra-seasonal variations in composition of samples from the same plot were equivalent to 25% frequently and 40% occasionally, of the annual means. These facts illustrate the difficulty of obtaining *fresh* pasturage of uniform quality for feeding trials.

The N content of timothy, mowed June 1, was not increased by 28 pounds of N but was raised by 56 pounds of N per acre applied annually in April. In this case, early cutting was a much more important factor than nitrogenous fertilizers.

On seeded, lawnmowed plots, the N, P, K, Ca, and Mg contents of pure stands of Kentucky bluegrass and Rhode Island bent grass were influenced appreciably by the source of fertilizer nitrogen. Materials carrying Na increased the K in the grasses, while magnesic fertilizers had the opposite effect. On this soil (pH 5.3), the use of physiologically neutral or alkaline N carriers resulted in higher N, P, and Ca contents in the grasses.

It is concluded that many carefully conducted feeding trials will be required before the results of chemical analyses of pasturage can be interpreted in terms of nutritional values.

EFFECT OF FREQUENCY OF CUTTING ON THE GROWTH, YIELD, AND COMPOSITION OF NAPIER GRASS[1]

C. P. WILSIE, E. K. AKAMINE, AND M. TAKAHASHI[2]

NAPIER grass (*Pennisetum purpureum* Schum.) has found an important place among the forage crops of Hawaii. It is a rank-growing, perennial grass, aggressive and persistent under tropical conditions. While used perhaps most extensively as a soiling crop, cut and fed green in feeding racks in the corral or barn, it has proved to be valuable as well for grazing under a system of proper pasture management (7).[3]

In pastures Napier grass is usually allowed to grow until it has reached a height of from 5 to 8 feet before grazing is permitted. Continuous grazing is then practiced or, if a rotational system is used, one paddock is grazed for several months without rest. Due to the size of the grass when cattle are turned in, there is a considerable tramping down of coarse stalks with a consequent loss or waste of forage.

An alternative scheme is to pasture early and often, never allowing the plants to produce coarse woody stalks which develop when maturity is approached. All of the forage may then be palatable and there is little waste. The quality of forage is therefore higher, but the stand may be seriously injured when the plants are not allowed to maintain enough top growth so that a strong crown and root system can be developed.

When used as a soiling crop, various cutting rotations are employed, from harvesting the crop as often as every 30 days to cutting as infrequently as every 4 or 5 months. Whether used for pasture or as a soiling crop then, it appeared evident that a study of the effect of cutting treatment upon the yield and composition of forage as well as the persistence of stand was highly important.

Paterson (2, 3), working in Trinidad, found that when Napier grass was cut at the age of 4, 8, and 12 weeks for a period of 48 weeks, the 12-week cutting rotation gave the highest green forage and dry matter yields. The protein and ash percentages decreased with an increase in the age of the plant. The 12-week cutting rotation was recommended on the basis of forage yields, nutritive value, and persistence of stand.

Later studies on the frequency of cutting by Paterson (4, 5) included, besides Napier grass, several other of the large tropical forage grasses and harvests were made every 45, 90, 120, and 180 days. In general, the longer the cutting rotation up to 6 months, the greater were the yields. The height of cutting as well as the period between harvests influenced the regeneration habit of the ratoon crops. Root

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[3]Figures in parenthesis refer to "Literature Cited", p. 273.

and tiller examinations showed that the short cutting rotations resulted in less vigorous stools and decreased root development. Paterson suggested that a cutting rotation of approximately 3 months and herbage cut from 6 to 10 inches above the ground resulted generally in rapid ratooning, multiple tillering, and a strong stool development. Yields of Napier grass (elephant grass) were greatly reduced by an infestation of a fungus, *Helminthosporium* spp.

In the Philippine Islands, Villegas (6) found that the productive life span of Napier grass cut every month at a height of 120 cm was about 3½ years. Joachim and Ponditteskere (1), after studying manuring and frequency of cutting of Napier grass, recommended a 6-week cutting rotation with a nitrogen application after each cutting.

EXPERIMENTAL

The object of the experiment reported here was to study the effect of the frequency of cutting Napier grass on the total forage, palatability of forage, chemical composition, and growth behavior under Hawaiian conditions.

A field experiment, laid out on the University of Hawaii farm, included five frequency of cutting treatments with eight replications arranged in randomized blocks. Each plot consisted of four rows 4 feet apart and 34 feet long. The whole area was planted uniformly to a vigorous strain of Napier grass on November 13, 1934, using stem cuttings with at least two eyes per cutting, spaced 2 feet apart in the row. The plant crop of all plots was harvested uniformly on February 19, 1935, after approximately 3 months of growth, and from this date the frequency of cutting experiment began. The cutting treatments were harvested every 6, 8, 10, 12, and 14 weeks for the duration of the experiment. The experiment was terminated on November 23, 1937, 144 weeks later.

CULTURAL METHODS

All plots received the same total annual application of a complete fertilizer including 180 pounds N, 72 pounds P_2O_5, and 48 pounds K_2O per acre. This amounted to 1,200 pounds of mixed fertilizer per acre per year, an equal portion of which (for any one cutting treatment) was applied after each harvest. The plots cut frequently had more applications per year, but all plots had the same total application.

Yields decreased sharply in spite of this fertilizer application so after March 16, 1937, the annual application was increased to 300 pounds N, 150 pounds P_2O_5 and 150 pounds K_2O, or a total application per acre of nearly 2,000 pounds of complete fertilizer per year.

Weeds were kept out by hand hoeing and the field was irrigated when necessary.

HARVESTING

All plots were cut by hand with cane knives, cutting to 2 or 3 inches above the ground level and border rows were removed before plot weights were taken. Green weights were recorded in the field directly after the plots were cut and samples were taken to be used later for the determination of moisture, chemical composition, and relative palatability.

RESULTS

FORAGE YIELDS

A summary of total yields of green and oven-dry forage, as well as the percentage of palatable material, for all cutting frequencies for the duration of the experiment is given in Table 1.

TABLE 1.—*Summary of forage yields and percentage palatability of Napier grass for duration of experiment (144 weeks).*

Cutting frequency	Green weight, tons per acre*	Oven-dry weight, tons per acre†	Average percentage palatable forage
6 weeks........	177.66	22.28	100
8 weeks........	230.41	33.37	89
10 weeks.......	250.65	39.16	68
12 weeks.......	280.65	47.84	52
14 weeks........	271.42	53.76	40

*A difference in treatment mean yields greater than 22.79 tons per acre is necessary for significance for a probability of 5%.
†A difference in treatment mean yields greater than 3.85 tons per acre is necessary for significance for a probability of 5%. At the 1% point a difference of 5.19 tons per acre is necessary.

Analyses of variance of both green forage and oven-dry forage yields showed that differences due to cutting treatment were highly significant. When the mean yields (oven-dry weights) of the various cutting treatments for the duration of the experiment were compared, it was found that within the range of cutting frequencies used, the longer the period between harvests, the greater was the yield of forage. The following significant order of yields of the different cutting frequencies existed even at the 1% point of probability: 14-weeks > 12-weeks > 10-weeks > 8-weeks > 6-weeks. These yield results confirm those obtained by Paterson (2, 3, 4) from the standpoint of effect of cutting treatment. The actual yields, however, were much higher than those obtained in Trinidad, approaching what Paterson has suggested as the possible maximum yield of a forage crop estimated at 20 tons of oven-dry forage per acre per annum (4).

When the yield data from successive harvests were examined, it was found that there was a sharp decline in forage production following the first ratoon crop. In spite of continued use of a liberal fertilizer application throughout the course of the experiment, the high initial yields were not maintained. This is very likely due to both the large quantities of nutrients removed from the soil and the effect of cutting on this rapidly growing, vigorous grass under tropical conditions. The trend in reduction in yield following initial cuttings is shown graphically in Fig. 1. After the first sharp decline, yields were maintained at a fairly constant level for the remainder of the experiment. The slight rise in yields at 120 weeks was no doubt caused by the increase in fertilizer applications made previous to these cuttings. (See section on cultural methods.)

QUALITY OF FORAGE

Samples of the whole forage were divided into palatable and unpalatable portions at the time green weights were recorded. The arbitrary division used was that of including in the palatable portion all

leaves and that part of the plant above and including the fifth visible ligule from the tip of the culm. The remainder or stemmy portion was called unpalatable. Feeding observations using whole plants had previously shown that this was a fairly accurate measure of palatability. It is fully recognized, however, that varying amounts of this coarse stemmy material might be palatable, depending upon whether the grass was fed whole or finely chopped, as well as the season of the year, the fertilizer used, and other factors. This mechanical division did give, however, a crude basis at least for comparing the relative amounts of palatable and unpalatable forage produced as a result of

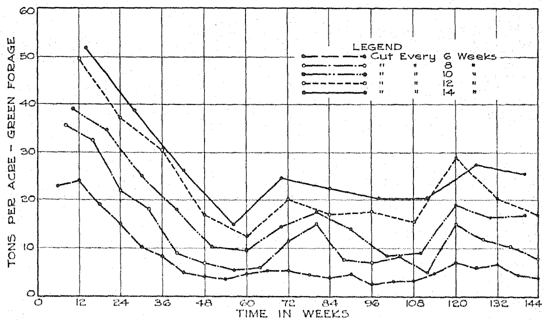

FIG. 1.—Yields of green forage in successive harvests of Napier grass under different cutting rotations.

the various cutting treatments. The average percentages of palatable portions of the total forage are given in Table 1, while the total yields of palatable and unpalatable forage as affected by cutting treatment are illustrated graphically in Fig. 2. The data indicate that palatability decreases rapidly as the cutting interval is increased.

CHEMICAL COMPOSITION

From samples obtained at each date of harvest, analyses of certain constituents were made on both the palatable and unpalatable portions of forage. The results are presented in summary form in Table 2.

Protein. Many dairymen and ranchers depend so largely upon green roughage for their principal feed that the protein content of forage becomes of considerable importance. An estimate of the protein produced per acre for the various cutting treatments is given in Table 3.

While there was no correlation between the yield of protein in the whole forage and cutting intervals, that fraction of the total amount produced which was present in the palatable portion of forage decreased considerably as the periods between cuttings increased. There appeared to be an especially marked drop between the 8- and 10-

TABLE 2.—*Average chemical composition of Napier grass on over-dry basis.*

Cutting frequency, weeks	Crude protein, %	Ether extract, %	Crude fiber, %	Ash, %	N-free extract, %	P_2O_5, %	CaO, %
In Whole Forage							
6	7.90	2.19	28.81	19.24	41.86	1.68	0.646
8	5.86	1.93	32.32	18.20	41.69	1.57	0.600
10	5.19	1.78	34.72	16.42	41.89	1.36	0.456
12	4.21	1.78	36.65	15.06	42.29	1.33	0.416
14	3.75	1.58	39.33	12.98	42.56	1.08	0.366
In Palatable Portion							
6	7.90	2.19	28.81	19.24	41.86	1.68	0.646
8	6.94	1.96	30.66	19.15	41.29	1.57	0.600
10	5.99	1.93	32.00	17.63	42.46	0.92	0.419
12	5.88	1.95	32.56	17.07	42.54	1.34	0.445
14	5.64	2.00	33.87	15.43	43.06	0.95	0.532
In Unpalatable Portion							
6	—	—	—	—	—	—	—
8	2.62	1.32	40.64	13.34	42.08	—	—
10	2.29	1.26	42.79	11.08	42.62	1.30	0.193
12	2.12	1.26	41.90	11.44	43.27	1.38	0.242
14	1.87	1.32	44.04	10.28	42.50	1.17	0.238

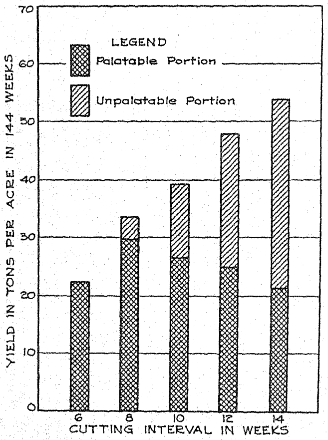

FIG. 2.—Oven-dry yields of palatable, unpalatable, and total Napier grass forage as affected by cutting frequency.

week cutting intervals. The steady drop in protein present in the palatable portion of forage from the 8-week to 14-week cutting intervals was due to the combined effect of the decrease in percentage protein and proportion of palatable portion as the cutting intervals were increased.

There was a marked increase in the amount of protein produced in the unpalatable portion as the cutting interval was increased.

The 8-week cutting interval gave the best results from the standpoint of yield of protein in the whole forage as well as in the palatable portion.

The percentage protein content decreased steadily in both palatable and

unpalatable portions as the cutting intervals were increased. The percentage composition of protein in the palatable portion was about three times as large as that of the unpalatable portion.

TABLE 3.—*Average number of stalks per hill and yield of protein per acre in all cutting treatments for duration of experiment.*

Cutting interval, weeks	Stalks per hill	Pounds of protein per acre		
		Whole forage	Palatable portion	Unpalatable portion
6	13.4*	3,494	3,494	0
8	23.5	4,040	3,726	314
10	25.0	3,440	2,730	714
12	26.6	3,834	2,848	986
14	23.0	3,500	2,289	1,212

*The number of new shoots coming up after harvest was always large, but most of these never attained such size as to be considered a stalk in the hill.

Crude fiber.—From Table 2 it is shown that the crude fiber content of the plant increased with the age at which it was harvested. Forage cut at 14 weeks of age had a crude fiber content nearly 40% higher than that cut at 6 weeks. The crude fiber content was materially higher in the unpalatable portion than in the palatable portion of forage for all cutting treatments.

Total ash.—The percentage of ash as shown in Table 2 decreased markedly as the plant matured, ranging from 19.24% in the whole forage at 6 weeks of age to 12.98% at 14 weeks. The palatable forage had a materially higher percentage of ash than did the unpalatable portions.

The data on chemical analyses compare favorably with the results obtained by other investigators (1, 2, 3).

GROWTH BEHAVIOR

The plant crop of Napier grass produced in 70 to 100 days after planting stem cuttings is tall, rank, and succulent. Relatively few stalks per hill are produced, the growth is rapid, the protein content in percentage is fairly high, moisture content is high, and the whole stalks are relatively palatable unless the plants have begun to bloom (7). After the plant crop is harvested, a vigorous stooling or tillering takes place and the development in succeeding ratoon crops is determined to a considerable extent by the severity of cutting treatment.

As has been explained by Paterson (4), Napier grass regenerates after cutting by two methods, either terminal or bud development. In young tillers, if the grass is not cut too close to the ground, the growing point of each tiller is not cut off and continued development produces new foliage. In this experiment the grass was always cut just above the ground level so that, with the exception of the 6-week cutting rotation, the regeneration must have come mainly from the development of dormant buds at the base of the tillers. This type of regeneration would tend to make the crown spread out more,

but recovery would probably be less rapid than if terminal regeneration could take place.

Under pasture conditions, where the plants are allowed to become somewhat mature and stemmy before grazing is started, much of the regeneration is confined to the terminal portion of the stem, a tuft of leaves developing at the nodes just below the place where the tip of a stalk has been chewed off.

Counts were made of the number of stalks per hill at each harvest. At the end of the experimental period these counts were averaged with the results indicated in Table 3.

The number of stalks per hill did not vary greatly with the exceptions of those produced by the 6-week cutting treatment. The grass on these plots started to recover very rapidly, but subsequent growth was slow and feeble. There was also an indication of a falling off in the number of tillers in the 14-week cutting treatment which may have been brought about as a result of excessive competition for moisture, nutrients, and sunlight.

Greater tillering, better recovery, and more vigorous growth were found on the plots cut at intervals of 8 weeks or more. Sufficient leaf area had been allowed to develop so that enough carbohydrates were synthesized and translocated to build up a strong crown and root system.

With an increase in age of the stand there was a tendency for plants to spread out by tillers and rhizomes from the original hill. This growth habit caused the appearance of bare spots in the center of many stools and it appeared that the plant might be dying. Examination of the underground parts of many such plants showed that the crown was alive in the center of the hill but was in a dormant condition. The grass cut at frequent intervals spread much less by rhizomes than did the grass cut less frequently.

It has been known for some time that too frequent cutting is disasterous to the highest production and persistence of many temperate zone forage species. The data presented have indicated that cutting treatment is of no less importance with tropical grasses under conditions of year-round rapid growth. It is essential then to find the proper balance between high protein, high mineral content, and high palatability, on the one hand, and high yield of dry matter and persistence, on the other. The results of this investigation have shown high forage yields, high palatability, and relatively high protein production in the grass cut every 8 weeks. The stand was satisfactory at the close of the experiment. Where fertilizers are applied after each harvest, a cutting rotation of about 8 weeks would therefore appear to be desirable. As there was an indication of seasonal effect on yields, it might be of advantage to increase the interval between cuttings to 10 weeks during the cooler winter months.

SUMMARY AND CONCLUSIONS

An experiment designed to determine the effect of frequency of cutting on the growth and chemical composition of Napier grass is described.

In production of forage an increase in the interval between harvests resulted in a higher total yield. Dry matter yields arranged themselves in this decreasing order: 14-week cutting interval > 12-week > 10-week > 8-week > 6-week.

There was some indication of a seasonal effect on forage yields.

The greatest amount of palatable forage was produced by cutting every 8 weeks .(An arbitrary mechanical division of forage into palatable and unpalatable portions was used.) The greatest amount of protein in the palatable portion of forage was produced by the grass cut at 6 and 8 weeks of age.

The percentage of palatable forage as well as the percentages of protein and ash (including phosphorus and calcium) decreased with an increase in the age of the plants.

The crude fiber percentage increased with an increase in the interval between cuttings.

The grass cut every 6 weeks was handicapped by poor recovery after each harvest, depleted stand, and greater weed competition.

When the factors of high yield, quality of forage, and persistence of stand are all considered, it would appear desirable under Hawaiian conditions to cut Napier grass every 8 weeks. It also seems likely that because of the seasonal effect, impossible to analyze adequately in the experiment described, a 10-week cutting interval might be used to advantage during the winter months when growth is slower. Such treatment should insure maximum yields of palatable, high quality green roughage, extending over a period of years without the necessity of replanting.

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INFLORESCENCE VARIATIONS IN BUFFALO GRASS, *BUCHLOE DACTYLOIDES*[1]

LEON E. WENGER[2]

SEVERAL interesting variations in the inflorescence of buffalo grass were noted during the summer and fall of 1939 in plants grown in the buffalo grass breeding nursery at the Fort Hays Experiment Station, Hays, Kansas.

Buffalo grass is largely dioecious, although a small percentage of the individuals are monoecious. Counts made in the breeding nursery during the last two years have shown that approximately 7% of the bulk population are monoecious, while 51% are pistillate and 42% are staminate.

FIG. 1.—Spikelet types occurring in 3-i Buffalo grass. *Left*, normal pistillate spikelet (1 floret); *center*, abnormal spikelet resembling a staminate spikelet but containing two pistillate florets (no stamens); *right*, normal staminate spikelet (2 florets).

The staminate inflorescence of buffalo grass, consisting usually of two or three short spikes, is borne on an erect slender culm protruding above the foliage. The pistillate inflorescence, consisting of two or three extremely short spikes, referred to commonly as burs, is normally produced rather obscurely on short culms among the leaves and is further hidden by being partially enveloped in the somewhat inflated sheaths of the upper leaves. The staminate spikelet has two flowers, whereas the pistillate spikelet normally has but one flower (Fig. 1).

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[1]Contribution of Fort Hays Branch of the Kansas Agricultural Experiment Station, Hays, Kansas, in cooperation with the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Contribution number 29. Received for publication January 26, 1940.

[2]Forage Crops Specialist, Fort Hays Branch Agricultural Experiment Station, and Agent, U. S. Dept. of Agriculture, in charge of forage crop investigations.

Buffalo grass with perfect flowers was noted first in 1938 at College Station, Tex., by Hensel,[3] and has since been observed at this station. This phenomenal character was noted here in a staminate plant, but in this instance not more than 2% of the total number of inflorescences contained perfect flowers. A few of the other inflorescences on this plant produced spikelets containing both staminate and pistillate flowers. Twelve seeds were produced in 1939 under open-pollinated conditions in the nursery and upon being planted in the greenhouse eight of these seeds germinated. The pollen from this plant is also known to be functional because in a cross where it was used a good amount of viable seed was produced.

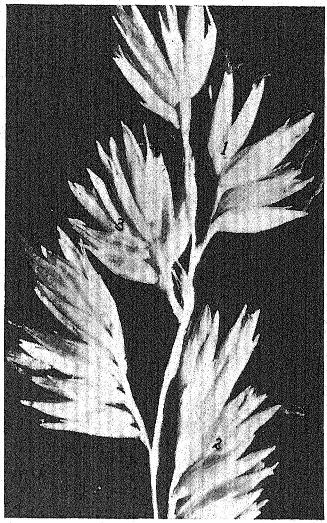

FIG. 2.—Variations in the inflorescence of buffalo grass noted in selection 3-i. Externally this appears to be a staminate inflorescence, but (1) shows a spikelet containing two pistillate florets, (2) shows a hermaphroditic spikelet containing a pistillate floret and a staminate floret, and (3) shows a normal staminate spikelet containing two staminate florets.

Other striking variations in the flowering habits of buffalo grass were noted in a pistillate plant selected for its tall seed-stalk character. This plant, started in 1936 from seed obtained from southern Oklahoma, produced only normal-appearing flower types in 1937 and 1938. On July 12, 1939, however, it was noted that a few off-type inflorescences were being produced on an increase planting of this selection where certain cultural treatments, namely, height and time of clipping as affecting the height and yield of seed, were being studied. Some of the variants contained both anthers and stigmas, but the florets upon being examined were found to be imperfect. The majority of these abnormal types appeared externally to be staminate. Close examination, however, disclosed four distinct variations. A few of the inflorescences contained staminate flowers in well-formed two-

[3]HENSEL, R. L. Perfect-flowered Buffalo grass, *Buchloe dactyloides*. Jour. Amer. Soc. Agron., 30:1043–1044. 1938.

flowered spikelets, but in these instances the spikes were much shortened and closely grouped. Some contained pistillate flowers in

FIG. 3.—Two types of inflorescences produced on buffalo grass selection 15-9-38. *Left*, normal pistillate inflorescence. *Right*, hermaphroditic inflorescence with peduncle and rachis elongated. Some of the lower spikelets produced only stamens, while some of the upper spikelets produced only seed.

malformed two-flowered spikelets (Fig. 1) and some contained spikelets with one pistillate and one staminate flower. Still other inflorescences had spikelets with all three variations (Fig. 2). Another type of variation was noted in pistillate inflorescences in which the rachis and peduncle were elongated thereby resulting in long open burs with the entire inflorescence extending beyond the upper leaves.

Whether the variations in this plant were the result of the cultural treatment, of the season, or of some genetic disturbance has not been determined. Possibly they were the result of a combination of all factors. Certainly the sex character in buffalo grass is complex and definitely unstable. No seed was produced in the off-type inflorescences, supposedly because of the excessively high temperatures which occurred simultaneously with anthesis. Very little seed was produced in the normal inflorescences even though these out-numbered the off-types many times, doutbless because of the same conditions.

This plant entered drouth dormancy during the latter part of July due to adverse conditions, but when temporarily revived by rains and cool weather during the week of August 7, it started to send out new inflorescences, some of which exhibited the earlier mentioned variations.

Still other variations were noted in a third selection during early September. In this instance the off-type inflorescences appeared in an increase planting which had been established by rooted nodes, but could not be found in the original pistillate plant which was still growing where originally set out in 1938 only a little distance away. The off-type flowering structures appeared externally to be staminate because they were produced on greatly elongated culms well above the foliage. Examination showed that these variations were of two types. In one the culm, peduncle, and rachis were all much elongated and the inflorescence contained only pistillate spikelets. In the other, aside from the various parts all being much elongated, the lower spikelets contained staminate florets and the upper spikelets contained pistillate florets. (See Fig. 3.) Seed was produced in both types of inflorescences. These variations appear to be the result of changes in the environment, inasmuch as the undisturbed parent clone produced neither variation in either 1938 or 1939.

It is of interest to note that all of the above-described variations occurred in dioecious plants and that the common tendency was for each plant to try and compensate for its sex deficiency by either producing flowering structures containing organs of the opposite sex or by producing structures that roughly assumed the form of the deficient sex inflorescence.

EFFECTS OF GRAZING UPON BUNCH WHEAT GRASS[1]

W. R. HANSON AND L. A. STODDART[2]

DURING the past decade much attention has been given to the great range lands of the West. These lands are inherently low in productivity because of aridity. Abnormal drought and constantly heavy use by livestock have caused the vegetation over much of the area to become greatly depleted. The forage has decreased in quantity, but more serious in many cases is the decrease in quality. Valuable species have been replaced by less valuable or even worthless ones. Because of the serious nature of these changes a number of ecological studies have been conducted on native grass to determine the reason for range deterioration.

The studies were made during the summer of 1938 in southern Cache Valley, Utah. The observed range occupies the benches and foothills above the more moist valley floor and is roughly comparable to the northern intermountain grasslands.

Originally bunch wheat grasses, *Agropyron inerme* (Scribn. and Smith) Rydb. and *Agropyron spicatum* (Pursh) Scribn. and Smith, were apparently dominant on the benches and alluvial fans.[3] Sagebrush, *Artemisia tridentata* Nutt., was generally subdominant to the grass but dominated the vegetation on some exposed slopes.

The present abundance of sagebrush on the heavily-grazed benchland and the sparsity of bunch wheat grass suggest invasion of sagebrush into climax grassland. Bunch wheat grass is scarce or lacking in many places along the benches. That this grass had been dominant is evidenced by the presence of an almost pure stand of wheatgrass on one side of a range division fence and almost pure sagebrush or sagebrush-weed on the other (Fig. 1). On parts of the range where grazing has been more moderate wheatgrass is still abundant, but it has undergone considerable reduction in number and size of plants.

The question naturally arises as to the causes within the plant which led to the disappearance or severe reduction of the wheatgrasses under current grazing practices. Investigators have recognized the importance of food accumulations in the economy of the plant; but other than the work done by McCarty (7, 8, 9)[4] and Aldous (1), little investigation of carbohydrate relationships of range forage species has been undertaken. This phase of the problem has to do with the permanence of the climax plants and the sustained yield of forage from year to year. Closely allied are the relationships of underground parts to longevity and forage yield. Because roots are less apparent and more difficult to study, they are often neglected in the consideration of a plant.

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[1]Contribution of the Range Management Department, Utah Agricultural Experiment Station, Logan, Utah. Received for publication January 30, 1940.

[2]Graduate Research Fellow and Research Professor of Range Management, respectively.

[3]*Agropyron spicatum* (Pursh) Scribn. and Smith, and *A. inerme* (Scribn. and Smith) Rydb. are differentiated by Hitchcock only by the presence or absence of awns. In some works *A. inerme* is considered as a sub-species.

[4]Figures in parenthesis refer to "Literature Cited", p. 288.

A sustained stand depends partly upon longevity of the plants and partly upon seed production and the subsequent establishment of the plants as seedlings. Seed crop, in turn, depends upon plant vigor, which in turn depends upon a sturdy root system and a store of carbohydrates to initiate strong growth in the spring.

FIG. 1.—Protected and overgrazed wheat grass range.

REVIEW OF LITERATURE

Clements, Weaver, and Hanson (6) established the fact that the kind and condition of the root system are the primary factors determining success in ecesis and subsequent competition. Weaver (12) pointed out that most root systems of prairie grasses deteriorate under heavy grazing and are less able to cope with drought and the rigors of winter.

Biswell and Weaver (4) studied the effect of frequent clippings upon the roots and tops of some prairie grasses. The size of both tops and roots was greatly reduced by this practice. Clipped plants failed to produce new rhizomes, and many old ones died. The length of roots was greatly decreased, and the relative production of roots was more greatly reduced than that of tops. The average weight of roots of clipped plants was 10.1% of the controls.

Flory and Trussel, cited by Calkins (5), studied the root habits of several southwestern grasses in their relation to soil conservation. The root systems of all these grasses were markedly decreased under heavy grazing.

McCarty (9) studied the march of carbohydrates throughout the growth of *Bromus carinatus*, *Elymus ambiguous*, and *Muhlenbergia gracilis*. Starch and sugars were found to be the most potent stored foods. In general, the starch and sugar content of roots and stem bases reached a maximum immediately following current seasonal growth, declined slightly during the rest period, and reached the minimum during the formative stages of shoot development. For incipient growth, both root and shoot, the plant depends completely upon the stored carbohydrate for energy and building material. The plant soon reaches the stage where it manufactures carbohydrate, but this carbohydrate is used by body processes as fast as it is manufactured. At the point where growth rate begins to decline, storage begins.

The limited studies that have been made show conclusively that reduction of the photosynthetic area during the growth period decreases the reserve of carbohydrate stored in the root and stem bases; and that this, in turn, reduces subsequent vigor and yield (1, 7, 10).

STUDIES ON ROOT DEVELOPMENT

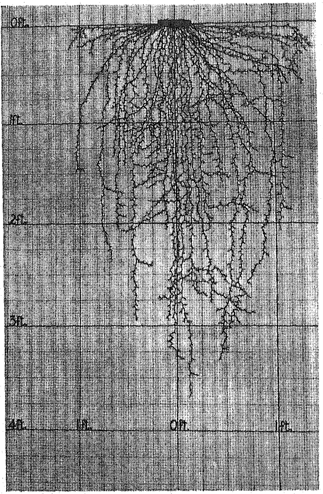

FIG. 2.—A representative root system of *Agropyron inerme.*

To determine the normal growth of the roots of *Agropyron inerme* and the effect of grazing upon the root system, studies were conducted along a division fence between a pasture and a protected field. Grazing was heavy on the one side and climax grasses were obviously depleted in both number and size. On the other side was approximately climax wheatgrass stand, grazed only in the autumn after cultivated crops had been harvested.

The roots were studied as dug from the walls of an excavation by means of an ice pick and later were charted (Fig. 2). The root system of undisturbed *Agropyron inerme* occupied the upper soil layers very effectively; the finer rootlets and root hairs, not shown in the chart, completely permeating the soil. Extending from the crown were numerous horizontal roots. The main body of roots, however, grew downward and fed in deep soil layers.

Maximum depth of the roots was fairly constant in each area, some roots penetrating to depths of over 180 cm, but lateral spread varied with available space. In the climax stand the root system of each plant contacted and, to a limited degree, intermingled with that of its neighbors. (See Fig. 3.)

In order to compare the root weight of normal plants with their top weight unit volumes of soil were collected under the plants, and the roots washed out by use of fine screens. By multiplying average volume of soil permeated by a plant by the average weight of living grass roots within that soil an estimate of the weight of the entire root system was obtained.

Most of the plant weight was actually underground. An average of estimations showed the underground parts to weigh about 13 times as much as the herbage. This estimation did not include root hairs and finer rootlets which passed through the screen during washing. Hence, root weight might have been appreciably greater had all root parts been included.

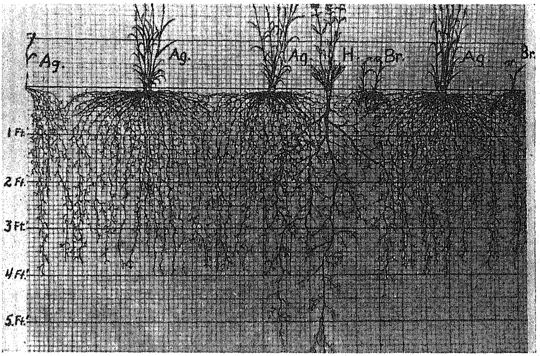

FIG. 3.—Bisect through climax stand of *Agropyron inerme*. Br, *Bromus tectorum*; Ag, *Agropyron inerme*; H, *Helianthella uniflora*.

To study the effects of grazing upon the roots, six plants were selected to represent grazed land and six protected land. A small trench was dug next to each plant and the main roots and branches were followed to their tips (Table 1). Maximum depth of the grass roots in this location was somewhat limited by a shallow soil; nevertheless, the root systems of grazed plants were unable to utilize the full depth of soil. Though average depth of the roots was 65 cm on protected

TABLE 1.—*Average maximum lateral spread and depth of roots of Agropyron inerme.*

Plant No.	Protected		Grazed	
	Depth, cm	Lateral spread, cm	Depth, cm	Lateral spread, cm
1	71	38	46	41
2	61	33	43	69
3	66	46	41	33
4	61	36	46	46
5	69	43	46	48
6	63	43	43	38
Average......	65	40	44	46

plants as compared to 44 cm on grazed plants, the lateral spread did not appear to be materially changed.

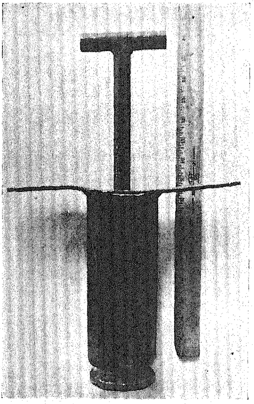

FIG. 4.—Tool for sampling root weight per unit volume of soil.

To determine the effect of grazing upon the root weight, a sampling tool was devised (Fig. 4). It consisted of a steel cylinder with a cutting edge and was fitted with a plunger. The handle of the plunger was marked to correspond to a given volume in the cylinder below the plunger.

A trench was dug alongside representative bunches of grass. The herbage was cut off. The sampler was placed over the center of the bunch and forced vertically into the soil until the mark on the handle appeared, which designated the desired volume enclosed within the cylinder. The soil was then cut away from around the cylinder and the enclosed soil and root mass severed from that below by a sharp knife. The plunger was used to remove the soil block to a paper bag. Samples were taken below the crown at levels of 0 to 15 cm, 15 to 30 cm, 30 to 45 cm, and 45 to 60 cm.

The soil blocks were taken into the laboratory where the soil was removed by water. Each block was placed in a fine-screen strainer and washed under the tap. When the soil was removed, the live grass roots were separated from the dead ones, other roots, and foreign material. This separation is a difficult process and was accomplished by washing, floating, and hand picking. Dead roots and live roots are easily distinguished only after some decay has taken place resulting in a color change. For this reason a few roots dead only a short period of time may have been included among the living roots. The grass roots were oven-dried and weighed, these weights being taken as an index of root development at a given depth.

The average index figure for grazed plants was 4.22 grams of roots per cubic decimeter, as compared to 25.85 grams per cubic decimeter for protected plants (Table 2). Therefore, the root development in the soil below protected plants was more than six times as great as below heavily grazed plants. Further, many root systems of heavily grazed grass plants failed to extend beyond a depth of 45 cm, while all protected plants had good root volume at and below this depth.

TABLE 2.—*Weights of Agropyron inerme roots from grazed and protected areas in grams per cubic decimeter of soil at various depths below the crown.*

Sample No.	Depth below the crown, grams				
	0–15 cm	15–30 cm	30–45 cm	45–60 cm	Total
	Plants from Heavily Grazed Area				
1	4.18	0.14	0.07	0.07	4.48
2	4.11	0.19	0.09	0.02	4.41
3	5.04	0.07	0.06	0.04	5.21
4	4.86	0.07	0.05	0.02	5.00
5	2.99	0.07	0.01	0.11	3.18
6	2.76	0.14	0.02	0.00	2.92
7	3.36	0.16	0.05	0.00	3.57
8	4.81	0.09	0.02	0.04	4.96
Average......	4.01	0.12	0.05	0.04	4.22
	Plants from Protected Area				
1	14.11	1.45	0.40	0.16	16.12
2	43.96	0.98	0.47	0.19	45.60
3	14.16	1.33	0.47	0.26	16.22
4	49.76	1.73	0.26	0.19	51.94
5	23.36	0.47	0.35	0.16	24.34
6	9.58	1.19	0.30	0.09	11.16
7	18.92	1.54	0.91	0.26	21.63
8	17.12	1.80	0.70	0.18	19.80
Average......	23.87	1.31	0.48	0.19	25.85

STUDIES ON HERBAGE PRODUCTION

To study the effect of grazing upon herbage production, a system of quadrats was laid out. Along the fence dividing the grazed and protected area a strip 20 meters wide and 200 meters long was delimited and subdivided into transects 2 meters wide, lying at right angles to the fence. Four of these were chosen for study. Each was divided into four square-meter quadrats. Within each transect two quadrats were chosen on the protected area and two on the grazed area. All choices were made at random. The basal area of *Agropyron inerme* was measured by the use of a pantograph. Average height and number of stalks per square meter were determined. The data from the measurements are summarized in Table 3.

TABLE 3.—*Basal area, height, and average number of stalks of Agropyron inerme under grazing and protection.*

Treatment	Av. basal area per sq. meter of ground, sq. cm.	Extremes, sq. cm.	Average height, cm.	Average no. of stalks per sq. meter
Grazed......	56.8	0–275	51	11.4
Protected....	538.5	0–1767	66.5	123.2

There was a very marked reduction in the above-ground parts of wheatgrass accompanying heavy grazing, as shown by a decrease in basal area, height, and number of seed stalks.

STUDIES ON SEED PRODUCTION AND GERMINATION

Seed samples for germination were collected from two locations, some from grazed plants and some from ungrazed. At the first location, eight samples of 10 heads each were collected in the near proximity of each of the plants studied for root production. The mature seeds were separated from the empty florets so that germination tests included only the filled seeds.

Duplicate germination tests were conducted in which moistened blotting paper in petri dishes was used as a planting medium. The number germinated was counted after 5 days and each second day thereafter until the 15th day, after which no germination took place. Conditions adhered to were those given by the *Association of Official Seed Analysts* (3).

Though seeds from grazed plants had a final germination average of 79.7% compared to 73.2% from ungrazed plants, the difference is not significant. At 5 days the germinations averaged 55.6 and 44.9%, respectively.

The second set of samples was obtained from the areas laid out in quadrats for the herbage study. All heads from each of 15-sample quadrats were collected. Percentage germination was determined as with the previous samples.

There was, as in the first test, no significant difference between germination of seeds from the grazed area and the protected, either at 5 days or at 15 days. The germination of seed from ungrazed plants was 21.3% at 5 days and 64.8% after 15 days (complete germination), whereas germination of seed from grazed plants was 21.3% at 5 days and 62.2% after 15 days.

However, Table 4 presents some important differences. The potentiality for reproduction by seed is many times greater for protected plants. The proportion of the florets that matured on protected plants exceeded that on the grazed area by 14.9%. Also, the viable seeds per square meter of ground were almost 50 times as numerous on the protected area.

STUDIES ON FOOD RESERVES IN ROOTS AND STEM BASES

The area laid out for herbage studies was used to obtain material for carbohydrate determinations. Four plants were selected from each of the transects, two being taken from each side of the fence. Those from the one side were protected plants, while those from the other were plants from a pasture grazed at an intensity of 7 acres per animal for 5 months. Since forage was more plentiful than usual, the grass plants were not grazed until after seed maturity. It is assumed, therefore, that any effect found upon storage of carbohydrate is chiefly attributable to the grazing of previous years.

Each plant was dug, freed of soil by means of a stiff brush, and the roots and stem bases clipped into small pieces. This material was placed in hot 95% alcohol for preservation until analyses were made.

TABLE 4.—*Seed heads, filled florets, percentage germination, and viable seeds produced on grazed and protected stands of Agropyron inerme.*

Plot No.	No. of heads per sq. meter	Filled florets Per sq. meter	Filled florets %	Germination 15 days, %	No. of viable seeds per sq. meter
		Grazed			
1	14.7	33.0	24.0	83.4	27.5
2	1.5	4.5	25.0	82.5	3.7
3	1.5	2.8	13.8	45.0	1.3
4	12.8	25.5	27.0	45.0	11.5
5	6.0	27.9	30.2	86.1	24.0
6	5.5	24.8	31.5	67.4	16.7
7	8.0	21.2	15.6	52.0	11.0
8	5.8	17.2	24.4	36.7	6.3
Average.	7.1	19.6	23.9	62.2	12.2
		Protected			
1	90.2	483.7	25.4	60.0	290.2
2	156.8	1053.4	39.8	81.5	858.5
3	123.5	968.1	42.6	74.5	721.2
4	63.2	582.5	46.7	76.0	442.7
5	174.2	1094.3	27.8	45.5	542.2
6	92.0	817.0	45.0	75.5	616.8
7	160.5	2099.3	47.2	46.5	976.2
8	102.5	682.6	36.2	58.5	399.3
Average.	120.4	972.6	38.8	64.8	630.2

The official methods (2) were used in the preparation and analysis of samples with the following exceptions: The reducing sugar was determined by the Shaffer and Hartman method (11); starch was hydrolysed by the use of saliva, as described by McCarty (7).[5] The carbohydrate fractions were computed in percent of moisture-free weight of the sample.

Percentages of ash, sugar, starch, and hemicellulose in the samples taken are shown in Table 5. The ash content of the two treatments was not significantly different. The combined sugar and starch fractions were, however, significantly higher for the protected plants. Variance due to treatments (grazing and protection) was significantly greater than error, and therefore, the mean of the protected area was significantly greater than the grazed.

The means of the total carbohydrates, including hemicellulose, are not significantly different. The f value for between treatments is 3.829, while an f value of 4.96 is required for significance. The factor causing a smaller difference here is the presence of the hemicellulose. The hemicellulose fraction then does not differ significantly between protected and grazed plants.

[5]It has been suggested that substances dissolved by saliva are not necessarily starch, but this method is believed by the authors to give results sufficiently accurate for comparisons.

TABLE 5.—*Ash and carbohydrate content of roots and stem bases of Agropyron inerme from grazed and protected ranges.*

Sample No.	Ash content, %	Carbohydrate				
		Sugars, %	Starch, %	Sugar and starch, %	Hemicellulose, %	Total, %
Grazed						
1 a	9.00	1.10	2.32	3.42	8.76	12.18
b		1.18	1.99	3.17	8.84	12.01
2 a	10.15	1.82	2.48	4.30	9.03	13.33
b		1.42	2.38	3.80	8.79	12.59
3 a	18.19	1.50	3.23	4.73	8.14	12.87
b		1.90	3.40	5.30	8.36	13.66
4 a	8.69	1.26	3.23	4.49	7.11	11.60
b		1.34	3.64	4.98	7.26	12.24
5 a	12.75	2.74	3.90	6.64	15.46	22.11
b		2.21	3.72	5.92	15.00	20.92
6 a	12.14	2.89	1.96	4.85	9.64	14.49
b		2.67	2.39	4.06	9.96	14.02
Average	11.82	1.84	2.89	4.64	9.70	14.33
Protected						
1 a	7.88	2.30	4.11	6.41	16.01	22.42
b		2.03	3.94	5.97	14.40	20.37
2 a	11.59	2.03	4.07	6.10	12.63	18.73
b		1.91	3.82	5.73	12.05	17.78
3 a	13.04	8.24	2.89	11.13	8.36	19.49
b		7.75	2.89	10.64	8.54	19.18
4 a	7.88	2.50	3.60	6.10	9.47	15.57
b		2.74	3.54	6.28	10.00	16.28
5 a	8.05	2.70	3.94	6.64	9.02	15.66
b		2.55	3.77	6.32	9.12	15.44
6 a	9.71	2.30	4.60	6.90	9.63	16.53
b		2.33	3.97	6.30	9.45	16.75
Average	9.69	3.28	3.76	7.04	10.72	17.77

DISCUSSION AND CONCLUSIONS

Agropyron inerme is especially well-adapted to grow in the semi-arid range lands of the northern intermountain regions of the United States. Moisture is the prime limiting factor in plant growth in this region, and the water balance of the plant determines largely its ability to exist. The extensive root system of *Agropyron inerme*, which practically fills the soil sometimes to a depth of over 180 cm, normally supplies water at a rapid enough rate to sustain the water balance of the plant. The shallow roots take advantage of light rains and the deeper roots reach the subsoil moisture reserves. This efficient root system, along with an ability to grow rapidly when moisture is available and the power to produce seed abundantly, enables *Agropyron inerme* to maintain itself in a semi-arid habitat if undisturbed.

Yet, under intense grazing, it yields its dominant position which it so ably holds if undisturbed. This study shows that changes brought about by overgrazing seriously alter the power of the plant to thrive in an arid environment.

Besides mechanical injury, the immediate deleterious effect of heavy grazing is the reduction of the photosynthetic area. The food resulting from photosynthesis is required to repair and build tissue in both roots and herbage and as food for energy release. A store of carbohydrate is required to carry the plant through its more or less dormant period and then to supply food for root growth and incipient herbage growth. Herbage removal leads to shortage of stored food and, hence, to poor root production and weakened growth in spring.

Furthermore, one year was insufficient for the plants to regain their normal food supply. Plants which were ungrazed during the season that samples were taken but which had been heavily grazed in previous seasons showed a food reserve reduction of 19.4% compared to protected plants. The explanation seems to be one of food relationships. When re-growth began, the food supply was drawn upon to replace dead roots and to initiate herbage growth. Due to a shortage of food in previously grazed plants, normal vigor was not attained, and, even though the plants were undisturbed for one season, food manufacture was inadequate to sustain a normal root system and replenish the supply as well.

The marked reduction in depth, spread, and intensity of ramification of the roots of heavily grazed plants as compared to roots of protected ones was the natural result of herbage removal during growth. Stored carbohydrates are the base materials for the manufacture of proteins and the complex carbohydrates used in cell structure. A dearth of carbohydrate, therefore, would result in reduction of the root system. The effect of a reduction of the root system upon the water relations is evident. Plants with depleted root systems are more susceptible to drought injury.

Agropyron inerme produced an average of 630 viable seeds per square meter of ground when protected. The effects of heavy grazing brought about a reduction to 12 in the number of viable seeds produced, and therefore materially lessened the chance for reproduction. Germination of seed, however, is not affected by grazing and resultant weakening of the plant.

The cause of reduction in size and numbers of *Agropyron inerme* plants on heavily grazed ranges lies largely in the following sequence of factors: (a) Removal of the photosynthetic tissue resulting in a dearth of stored food in roots and stem bases, (b) a depletion of the root system and lack of vigor in the next year's plant, (c) the reduced root system and lack of vigor in the early season leaving the plant more susceptible to drought injury, (d) fewer viable seeds decreasing the possibility of reproduction. These results act cumulatively and depletion of the stand is progressive.

SUMMARY

Agropyron inerme was studied on range land in Cache Valley, Utah. Studies were made on protected and heavily grazed areas to compare root development, herbage and seed production, and content of sugar, starch, and hemicellulose in roots and stem bases.

The habits of growth of the roots of *Agropyron inerme* are well adapted to its habitat and insure the species a place as dominant in the area studied. The soil mass below normal plants was thoroughly permeated from a depth about 5 cm to as deep as 180 cm. Root weight was 13.1 times top weight.

The average weight of roots per cubic decimeter of soil was 25.85 grams on protected range and 4.22 grams on heavily grazed range, a reduction to about one-sixth the normal. Maximum depth of roots of grazed plants was materially reduced.

There was a very marked decrease in the above-ground parts of wheatgrass accompanying overgrazing as evidenced by reduced basal area, height, and number of seed stalks.

Germination tests of filled florets taken from protected and heavily grazed range showed no significant difference. On protected range 38.8% of the florets matured and on heavily grazed range 23.9% matured. There were 630.2 viable seeds per square meter of ground produced on protected range and 12.2 on the heavily grazed area.

Stem bases and roots of plants protected from heavy grazing in previous years contained 17.77% sugar and starch, while those of plants grazed heavily in previous years contained 14.33%. The hemicellulose content was not significantly different.

This study leads one to conclude that *Agropyron inerme* could have been dominant on much range land in Cache Valley where it is at present scarce or wanting, and general observations indicate that it was dominant. Sustained yield of *A. inerme* depends predominantly upon extent, intensity of ramification, and carbohydrate content of the root system. This study emphasizes the importance of controlled grazing.

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SOIL AND EROSION CHANGES ON THE DALHART SAND DUNE AREA[1]

LUTHER K. EBY AND CHARLES J. WHITFIELD[2]

IN the past few years, certain areas in the southern Great Plains have suffered from extreme wind erosion with the subsequent formation of sand dunes. In 1936, an experimental area was established in Dallam County, Texas, which is known as the Dalhart Sand Dune Area. This site, consisting of 2,000 acres, was selected as being typical of a large number of similarly wind-eroded areas. The results of studies dealing with the methods of stabilization and utilization of this sand dune area have been reported by Whitfield.[3] In April 1936, a Soil Conservation Service survey was made on this experimental area prior to treatment.[4] In August 1939, another survey was made on a portion of the area (925 acres) to obtain information of a specific nature as to the changes in soil and erosion that had occurred in the interval of about 3½ years.

Before examining these two surveys, it might be well to note in a general way the nature of the soils occurring on the area and to suggest the nature and probable causes of this particular type of wind erosion.

DESCRIPTION OF SOILS

The soils occurring on the area are characterized by a light brown to brown, sandy surface soil and a reddish brown sandy loam to sandy clay subsoil. In structure the surface soils are single grained and the subsoils are massive with a slight tendency to form columns. Of particular importance is the property of these subsoils to become very compact when dry. When they are exposed by erosion, they form an extremely hard, smooth surface. These soils are of a medium depth to deep, varying in the depth to calcareous material from about 2 to 5 feet. Small areas with lime at or near the surface are common. The areas, if large enough, are mapped as a shallow phase or as another series. Another variation is the occurrence of buried lake beds. These old lake beds are generally 2 feet or more below the surface and consist of a very dark, heavy, plastic clay. Such areas are for the most part quite small and are not delineated in ordinary Soil Conservation Service surveys, but are of importance in the present detailed study.

Two soil types, a fine sandy loam and a loamy fine sand, were mapped on 55% of the area.[5] The remainder of the area, due to severe

[1]Contribution from the Soil Conservation Service, U. S. Dept. of Agriculture, Amarillo, Texas. Received for publication February 6, 1940.

[2]Junior Soil Technologist and Senior Soil Conservationist, respectively.

[3]WHITFIELD, CHARLES J. Sand dunes of recent origin in the southern Great Plains. Jour. Agr. Res., 56:907. 1938.

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[4]Original survey by Dave R. Cawlfield and Claude L. Fly, Soil Conservation Service.

[5]The two soil types would probably be correlated as Dalhart fine sandy loam and Springer loamy fine sand. These two series are differentiated entirely on subsoil texture. The Dalhart series has a sandy clay loam to sandy clay subsoil and the Springer series has a sandy loam to a sandy clay loam subsoil.

wind erosion with a subsequent loss of all of the topsoil, was mapped as eight subsoil types and dune sand. The subsoils have been grouped as follows:

1. Old lake beds consisting of a heavy, plastic, bluish-grey clay. After these lake beds have been exposed, very little additional erosion seems to occur, as evidenced by the fact that in some instances these areas are considerably higher than the surrounding subsoils. Three per cent of the area was mapped as this subsoil type.
2. Subsoil types with an estimated removal of from 8 to 15 inches. The surface of these subsoils is extremely hard and fairly smooth. Present surface texture varies from a sandy clay loam to a light clay. Erosion probably continues to remove some of the surface but at a much slower rate. These subsoil types were mapped on 17% of the area.
3. These subsoils are similar to those just mentioned except that they are much more severely eroded, having lost an estimated 2 to 5 feet of soil. This increased and variable erosion may be due to the fact that the original soils were lighter in texture and contained shallow areas. The surface is somewhat less compact than on the above group and varies in texture from a sandy loam to a sandy clay loam. These subsoils are generally calcareous. This group was mapped on about 8% of the area.
4. This subsoil presents an extremely severe case of wind erosion, the entire soil profile having been removed, leaving material consisting principally of soft caliche. Less than 1% of the area was occupied by this subsoil type.

Areas with a covering of sand varying from 2 to 3 feet up to 26 feet in the case of the largest dune were mapped as dune sand. This material consists of a rather heterogeneous mixture varying in texture from a loamy fine sand to a sand. It exhibits slight compaction in places but is for the most part extremely loose and friable. This dune sand was mapped on 16% of the total area.

Thus we find that about 45% of the area not only produces no vegetation, but presents an extreme hazard to the surrounding areas. This lack of vegetation is due to constant shifting of the sands on the dunes and to the hard smooth surface of the subsoils which present a clean sweep for the cutting action of the sand laden winds.

TYPE OF WIND EROSION

The type of wind erosion and dune formation with which we are here concerned should not be confused with dune formation occurring on sands. The latter is not of recent origin and occurs on deep, loose sands, derived in most cases from aeolian deposits. Furthermore, these dunes are fairly well stabilized by native vegetation. The dunes formed on the soil series already described, as well as on other series of a similar character, are of recent origin. They owe their formation to conditions of drought and over grazing. On the Dalhart Sand Dune Area, the origin is believed to be an 80-acre field. This field was cultivated from 1907 to 1914 and was then used for grazing. Prior to the

present studies, the experiment area had never been under cultivation except for this 80 acres.

An examination of the original survey indicates the presence of four rather distinct erosion types, *viz.*, (1) slight removal and shallow accumulations, (2) slight to moderate removal and moderate to severe accumulations, (3) severe to very severe removals and little or no accumulations, and (4) the sand dunes (Fig. 1).

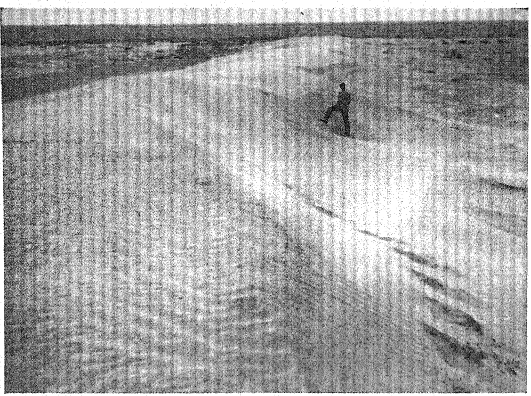

FIG. 1.—A view of sand dunes on the Dalhart Substation. In the background is the original vegetation; in midground slight to moderate removal and accumulations; and in the foreground are sand dunes.

These areas form a more or less definite pattern, starting with erosion type 2 and proceeding in a northeasterly direction in the order 2, 3, and 4. Type 1 which, comparatively, has not been greatly affected by erosion lies to the south and east of the other erosion types. There is, of course, some overlapping of these types. This is particularly true in the case of 3 and 4. The severely eroded and bare areas extend between the dunes. This arrangement of these erosion types probably is due to the direction of the prevailing winds which are from the south and southwest.

Reconstructing the probable sequence of erosion, we have first the original source which in this case was an old plowed field. Top-soil from this source moves in a northeast direction and is caught on adjoining areas in small hummocks or is fairly well distributed over the area. At any rate, enough sandy material moves in to give a decrease in vegetation on the new area, thus producing still more erosive material. The hummocks form still larger hummocks which finally coalesce, forming small dunes. These dunes continue to grow in size

as they move forward until large severely eroded areas are left in their wake. As these dunes continue to grow in size, their movement

FIG. 2.—The smooth subsoil surfaces between the dunes were listed to promote vegetative growth.

FIG. 3.—Vegetation, planted around the dunes, catches and holds drifting sand; remaining sand areas finally level out in the established cover crops.

becomes very much slower. However, some of the dune material is carried beyond the dunes, forming a new area of rather severe accumulations so that the process of dune formation is again repeated.

CHANGES DUE TO TREATMENT

All of the various methods to reduce the size of the dunes, as the first step in stabilization, depend primarily on wind action. The smooth subsoil surfaces between the dunes are listed both to form a rough surface to hold the sand and to promote vegetative growth which will catch and hold still more sand (Figs. 2 and 3). It should be kept in mind that the lack of vegetation is not due to any lack of productive capacity in either the subsoils or the dune sand. However, the spreading of sandy material over exposed subsoils and the subsequent mixing of these materials by cultivation tends greatly to improve these soils from a purely physical standpoint. The resulting soil not only has a fairly high water-holding capacity but a high rate of absorption as well. The only exceptions are subsoil type 1 (old lake beds) which will support little vegetation due to its droughty condition and subsoil type 7 (raw caliche). These two types occupy about 3% of the area. They require a covering of sandy material before much vegetative growth can be induced.

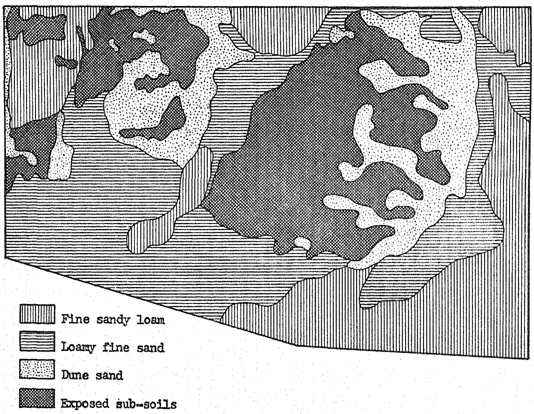

FIG. 4.—Soil types and severely eroded areas in April, 1936, on the Dalhart Sand Dune Area. Scale, 4 inches = 1 mile.

The important changes in soils that have occurred may be noted by a comparison of the two maps (Figs. 4 and 5). The changes in both soils and erosion are summarized in Table 1. Dunes more than 6 feet in height, originally occupying an area of 45 acres or 5% of the total area, were reduced to one small dune of about ½ acre which was just over 6 feet in height. The area occupied by dunes from 3 to 6 feet in height was subsequently increased from 13 acres to 23 acres.

However, these smaller dunes have lost most of their dune characteristics in size, shape, and compaction, and have become partially or completely stabilized. The area originally mapped as exposed subsoils was reduced from about 260 acres, or 28% of the total area, to 45 acres. This remaining subsoil area is confined principally to a portion of the area on which no treatment was applied other than the accumulation of sand from the surrounding treated areas. This accumulation has brought about vegetative growth so that less than 1% of the total area now consists of "bare" subsoils. An increase in accumulations in the less eroded areas was observed. This occurred principally in that portion of the area adjacent to the dunes. These accumulations are in the form of hummocks and cover less than one-third of the area involved.

TABLE 1.—*Changes in soils and wind erosion on the Dalhart sand dune area.*

Soils	Apr. 1936, %	Aug. 1939, %
Loamy fine sand	24	32
Fine sandy loam	31	38
Loamy fine sand (shallow phase)	—	6
Dune sand	17	18
Subsoil No. 1	3	3
Subsoil No. 2	18	1
Subsoil No. 3	7	2
Subsoil No. 4	—*	—*
Wind erosion:		
Accumulations:		
6–12 in.	4	—
12–36 in.	13	—
36–72 in.	1	6
72 in. and above	5	—*
Removals:		
A horizon and portion of B horizon	18	—*
Lower B horizon and portion of C horizon	5	—*
Removals and accumulations:		
Removal less than 25% of A horizon; accumulations less than 6 in.	17	1
Removal less than 25% of A horizon; accumulation 6–12 in.	4	—
Removal, 25–75% of A horizon; accumulation less than 6 in.	4	7
Removal, 25–75% of A horizon; accumulation 6–12 in.	20	25
Removal, 25–75% of A horizon; accumulation 12–36 in.	4	34
Removal, A horizon and portion of B horizon; accumulation less than 6 in.	—	8
Removal, A horizon and portion of B horizon; accumulation 12–36 in.	1	12
Removal, lower B horizon and portion of C horizon; accumulation less than 6 in.	—	3
Removal, lower B horizon and portion of C horizon; accumulation 6–12 in.	4	—
Removal, lower B horizon and portion of C horizon; accumulation 12–36 in.	1	2

*Less than 1%.

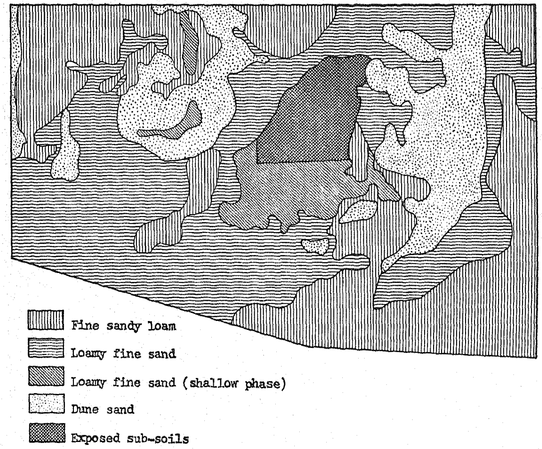

FIG. 5.—Soil types and severely eroded areas in August, 1939, on the Dalhart Sand Dune Area. Scale 4 inches = 1 mile.

It is rather difficult to say just when enough erosion changes have taken place to produce another soil type. However, the following differences were noted in a comparison of the two surveys: The fine sandy loam was increased from 24% to 32%. This change, as has already been noted, was due to the deposition of soil material on exposed subsoil and the subsequent distribution and mixing with the subsoil. The loamy fine sand was increased from 31% to 38% for the same reason as given above. The subsoils suffering from extreme erosion were mapped as fine sandy loam (shallow phase), less than 1%, and loamy fine sand (shallow phase), 6%. No change was noted in the amount of subsoil types 1 and 4. Some shifting of the dune sand occurred although the total acreage remained about the same.

SUMMARY

The changes that have occurred over a period of 3½ years in soils and erosion on a severely wind-eroded area have been presented. It is rather difficult to express these changes quantitatively. However, an attempt has been made to show that, although these medium textured to sandy soils have suffered from extreme wind erosion, the treatment applied has sufficiently modified their physical condition so that their productive capacity very nearly equals the productive capacity prior to accelerated wind erosion.

BORON DEFICIENCIES AS REVEALED BY PLANT AND SOIL TESTS[1]

K. C. BERGER AND E. TRUOG[2]

WHEN boron becomes deficient certain external and internal changes occur in plants, such as heart and dry rot of sugar beets, black spot of garden beets, brown heart of turnips, cracked stem of celery, corky core of apples, and yellowing of alfalfa. However, before these symptoms show up in the plants, a reduction in yield usually takes place. Since certain plants, such as the legumes and many truck crops, require more boron than other plants, notably the grasses, they can be used to better advantage as indicator plants.

The amounts of boron found in plant tissue give some indication of the amounts of available boron in the soils on which the plants were grown. Results presented by the authors in a previous paper[3] show that alfalfa plants provided with a plentiful supply of available boron contained from 30 to 50 p.p.m. of boron in the dry tissue, while those provided with an insufficient supply for normal growth contained only 8 p.p.m. Similarly, when beets were grown on a soil low in available boron, they contained only 14.5 p.p.m. of boron, while the beets grown on this same soil which had been fertilized with boron contained 24 p.p.m.

METHODS AND MATERIALS

The quinalizarin color reaction described by the authors[4] was used in all the boron determinations. The available boron of soils was extracted by refluxing 20 grams of soil with 40 cc of water for 5 minutes. An aliquot of the filtered extract was then made alkaline and evaporated to dryness. The residue was ignited to destroy organic matter and nitrates and then taken up with dilute acid, after which the quinalizarin colorimetric test for boron was applied.

In the determination of total boron in soils a sodium carbonate fusion was made and the resulting melt was dissolved at pH 5.5 to 6.0 with sulfuric acid. The resulting solution was made up to 500 cc with alcohol, centrifuged, and an aliquot made alkaline and evaporated to dryness. After ignition and dissolving in dilute acid, the quinalizarin test was applied.

In the determination of total boron in plants, the plant tissue was ignited to a gray ash, which was taken up with dilute acid. The quinalizarin test was then applied to some of the clarified extract.

The beets which were analyzed were grown on experimental plats, the soil of which is a Poygan silty clay loam.[5] The surface soil to a depth of 6 inches consists

[1]Contribution from the Department of Soils, University of Wisconsin, Madison, Wis. Published with the permission of the Director of the Wisconsin Agricultural Experiment Station. Presented before the Division of Fertilizer Chemistry at the ninety-eighth meeting of the American Chemical Society in Boston, Mass., September 11–15, 1939. This work was supported in part by a fellowship grant from the American Potash Institute, Inc. Received for publication February 6, 1940.

[2]Fellow and Professor of Soils, respectively.

[3]BERGER, K. C., and TRUOG, E. Ind. Eng. Chem., Anal. Ed., 11:540. 1939.

[4]*Loc. cit.*

[5]The authors are indebted to Dr. J. C. Walker and his associates for making available from these plats the samples of soil and figures relative to the incidence of black spot.

of black friable silty clay loam with some fine sand. The subsoil consists of a dull-red clay which is calcareous. Part of the field on which the plats were laid out had been limed previously and the reaction of the plats varies from pH 6.0 to 8.0 The plats all received a basic treatment of phosphate, nitrogen, and potash, and in addition they received various amounts of borax ranging from 0 to 60 pounds per acre. All treatments were quadruplicated.

PLANT TESTS

Fig. 1 gives results showing the relationship of the amounts of boron found in red beet leaves to the amounts of available boron found in the soil on which these beets were grown. There appears to

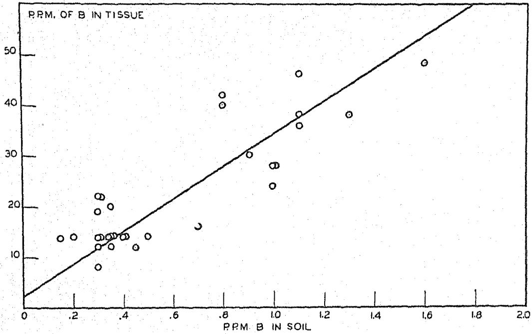

FIG. 1.—Relationship of available boron in soils to total boron in plant tissue of red beet leaves.

be a good correlation between the amounts of available boron found in the soil and the amounts of boron found in the dried beet leaves. Analysis of plant tissue thus offers some promise as a method of determining the level of available boron in soils.

SOIL TESTS

The boron present in soils may be divided into three categories, namely, total boron, acid-soluble boron, and water-soluble boron. The total boron content of a soil is not a good indicator of the adequacy or need of boron fertilization, because generally, less than 5% of the total boron in soils is in an available form. The unavailable portion is often present largely as tourmaline. Experimental tests indicate that tourmaline is not very available to plants. Fig. 2 shows sunflower plants which were grown in nutrient solutions similar in all respects with the exception of the boron content. Culture A received no boron other than that found in the seed and as impurities in the chemicals. The plants are small and growth has ceased. Culture B

received 0.5 gram of 100-mesh tourmaline. A small amount of growth was made over that produced in culture A, but the terminal bud is dead. Culture C is a normal sunflower plant which received 1.0 p.p.m. of boron in the form of boric acid in the nutrient solution.

The amount of acid-soluble boron found in soils may be larger or smaller than the amount of boron extracted with boiling water. It was found that the concentration of acid used, the method of agitation during extraction, and the temperature at which the extraction is conducted affect the final result.

Table 1 gives the amounts of boron extracted by various solvents from the soil taken from a number of the experimental plats and

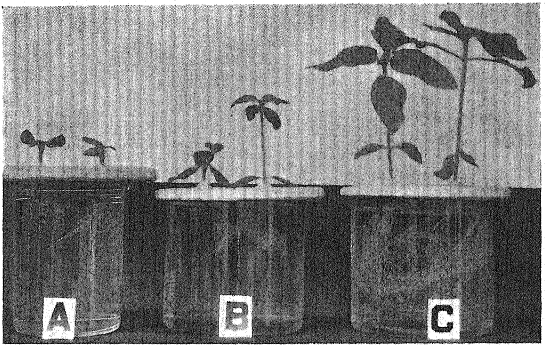

FIG. 2.—Sunflowers grown in water cultures. A, no boron added; B, 0.5 gram of 100-mesh tourmaline added; and C, 1.0 p.p.m. B as boric acid added.

also the percentages of black spot present in the beets grown on these plats. There apparently is little correlation between the amounts of total boron found in the soils and either the amounts of water-soluble boron or acid-soluble boron. Neither is there a good correlation between the amounts of acid-soluble boron and the percentages of black spot which occurred.

Difficulties are encountered in acid extractions with soils containing large amounts of free calcium carbonate, because such soils may completely neutralize a dilute acid used in the extraction. Furthermore, if a stronger acid is used, the resulting extract will contain such a large amount of salt that a laborious and time-consuming process is encountered in separating the salt before the boron can be determined.

The amount of boron extracted from a soil by boiling 20 grams of soil with 40 cc of water for a period of 5 minutes appears to correlate fairly well with crop responses to boron fertilization. In Fig. 3 the amounts of boron extracted by this method are plotted against the indexes of black spot in red beets. The index of discoloration is a

TABLE 1.—*Amounts of boron extracted from soils with various procedures.*

Plat No.	Borax applied per acre, pounds	pH	Equivalent $CaCO_3$ present, %	Beets affected with black spot, %	Amounts of boron found				
					Water extraction p.p.m.*	Acid extraction p.p.m.†	Acid extraction p.p.m.‡	Acid extraction p.p.m.§ tion	Total p.p.m.‖
II–10	0	8.0	9.5	98	0.3	0.2	0.9	0.2	13
II–9	20	8.0	9.5	35	0.6	0.3	0.45	0.3	14
I–1	20	6.0	0.0	5	1.5	0.7	2.2	1.3	17
II–2	20	6.2	0.0	11	1.6	0.8	2.7	1.8	10
II–7	40	8.0	2.5	39	0.5	0.8	1.9	1.0	12
II–1	40	6.0	0.0	13	1.8	0.8	2.5	1.6	11
III–1	40	6.2	0.0	16	1.1	0.8	2.3	1.9	15
II–4	60	7.8	1.5	2	2.0	1.4	5.2	4.2	11

*The water extraction was made in accordance with the method of extraction of available boron previously described in this paper.

†Acid extraction involved treatment of 20 grams of soil with sufficient sulfuric acid to neutralize carbonates present and to give an excess of 1.0 cc of 1.0 normal sulfuric acid in all cases. The volume of acid was adjusted to 40 cc with distilled water and the samples were shaken for a period of 30 minutes.

‡Acid treatment involved the same proportions of soil, acid, and water but the samples were boiled for 5 minutes, under a reflux condenser, instead of shaken for 30 minutes.

§Acid treatment consisted of shaking 20 grams of soil and 40 cc of 0.1 normal sulfuric acid for a period of 30 minutes.

‖The determination of total boron in the soil was made in accordance with the method previously described in this paper.

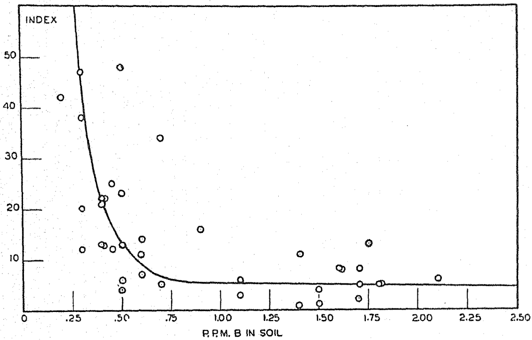

FIG. 3.—Comparison of amounts of available boron in soils to black spot index in beets.

combination of the percentage of beets affected with black spot and the severity of the blackening. Walker and his associates[6] describe the method of determining the index and state that an index of 0

[6]WALKER, J. C., JOLIVETTE, J. P., and MCLEAN, J. G. Canning Age, 19:489. 1938.

indicates that there is no blackening whatsoever, while an index of 100 indicates that all of the beets are severely blackened. The index appears to give a somewhat better indication of the degree of the boron deficiency than does the percentage of beets affected with black spot alone. Considering the numerous factors involved, the correlation between the percentages of black spot found in the beets and the amounts of water-soluble boron found in the soils appears to be fairly satisfactory.

SUMMARY

The amount of boron present in the leaves of table beets gives an indication of the amount of available boron present in the soils on which the beets were grown. Thus, plant tissue analysis for boron may be used to determine the level of available boron in soils.

The boron present in soils may be divided into three categories, namely, total boron, acid-soluble boron, and water-soluble boron. Results of analyses show that the total boron content of a soil is not a reliable indicator of the need for boron fertilization because, generally, less than 5% of the total boron is in available form. The unavailable, or better, difficultly available, form is often present largely as tourmaline. The acid-soluble boron content of a soil gives a somewhat better indication, but does not appear to correlate as well with the incidence of black spot in garden beets as does the amount of boron extracted with boiling water. Furthermore, acid extractions introduce difficulties in the case of calcareous soils, since these may neutralize all or a part of the acid. Extraction by treatment of the soil with boiling water for 5 minutes appears, at the present, to be the best method of extracting what may be called the available boron in soils.

LEAF PIGMENT CONCENTRATION AND ITS RELATION TO YIELD IN FAIRWAY CRESTED WHEAT GRASS AND PARKLAND BROME GRASS[1]

I. J. JOHNSON AND ELMER S. MILLER[2]

AMONG the various plant pigments found in green leaf tissues, chlorophyll has been the subject of extensive investigation in greenhouse and laboratory researches. Field experiments on the relation between chlorophyll concentration to yielding ability in corn have been reported by Sprague and Curtis (7)[3] and by Miller and Johnson (4). In the previous study (4), there was no significant correlation of chlorophyll concentration or carotenoid concentration and yield among inbred lines and single crosses in field and sweet corn.

The carotenoid pigments in forage crops are of special interest because certain ones possess vitamin A activity. Among the yellow pigments found in plant material (6), only alpha, beta, and gamma carotene and cryptoxanthin possess vitamin A activity. In green leaf tissue, beta carotene is the principal source of vitamin A, one molecule being equivalent to two possible molecules of vitamin A. Leaf xanthophyll and zeaxanthin, the dominant yellow pigments in green leaf tissue, possess only a slight, if any, vitamin A activity.

The present study was made with forage grasses to determine the extent to which chlorophyll and carotenoid pigment concentrations varied among clonal lines and to determine the possibilities of breeding strains of superior nutritive value. Additional information on the relation between chlorophyll concentration and yield seemed desirable.

MATERIAL AND METHODS

The material analyzed for pigment concentration and yield consisted of a group of 55 clonal lines of Fairway crested wheat grass and 76 of Parkland brome grass. These lines came from individual plants selected in 1937, subdivided, and transplanted in duplicate 4.5 foot rows at University Farm, St. Paul, and at the Waseca branch station.

Leaf samples from fully headed plants were collected in each of the duplicate plots grown at University Farm. All plots were sampled on the same day. Each sample for pigment analysis consisted of seven to eight leaves, selecting the third leaf from the top to overcome a possible variability due to positional effect on the plant. Three samples were taken from each row, placed in a glass vial, stoppered, and immediately frozen in the field with dry ice. The frozen samples were then

[1]Contribution from the Divisions of Agronomy and Plant Genetics and Botany, University of Minnesota, St. Paul, Minn. Paper No. 1782 of the Journal Series, Minnesota Agricultural Experiment Station. Aided by a grant from the Graduate School of the University of Minnesota. Assistance in the preparation of these materials was furnished by the personnel of Works Project Administration Official Project No. 65-1-71-140, Subproject No. 331, and Project No. 665-71-3-69, Subproject No. 409. Received for publication February 19, 1940.

[2]Professor and Research Professor of Farm Crops, Iowa State College, Ames, Iowa, Formerly Associate Professor of Agronomy and Plant Genetics, University of Minnesota, and Assistant Professor of Botany, University of Minnesota, respectively.

[3]Numbers in parenthesis refer to "Literature Cited", p. 306.

stored 4 months at $-15°$ C before they were studied. Of the three samples, one was used for analysis, one for dry matter determination, and the third preserved for use as a re-check if needed. The sample for analysis (0.5 to 1.0 gram) was weighed, moistened with acetone, ground with washed sand in a mortar, and the pigments extracted immediately with acetone for 1 hour in a Goldfisch extractor. The acetone solution of pigments was then transferred to an ether solution in a separatory funnel. The concentration of chlorophyll, total carotenoids, and Beta carotene were determined spectrophotometrically according to the method described by Miller (3). All reported results on pigment analysis are based on a dry weight basis.

The yield of the clonal lines in tons per acre on a green weight basis are based on the average of the two replicates grown at University Farm.

EXPERIMENTAL RESULTS

VARIABILITY IN PIGMENT CONCENTRATION AND YIELD

From the analyses of variance of the results obtained in the study of pigment concentration and of yield in duplicate plots, a frequency distribution of the clonal lines was made to show the extent of their variability from the mean of their population. The classes used were made on the basis of the standard error of a difference ranging from five times the standard error of the difference above and below the mean. The distribution of the strains of Fairway crested wheat grass and Parkland brome grass in Table 1 shows a wide range in variability for the pigments studied.

In Fairway crested wheat grass the strains varied in percentage of total carotenoids from four times the standard error of the difference below the mean to five times the standard error of the difference above the mean. The strains ranged from 13.1×10^{-4} to $32.0 \times 10^{-4}\%$ total carotenoids on a dry weight basis.

In beta carotene concentration, the strains varied from five times the standard error of a difference below the mean to five times the standard error of a difference above the mean and ranged from 3.8×10^{-4} to $10.5 \times 10^{-4}\%$ on a dry basis. For total chlorophyll, the range in distribution of strains was likewise very large. Although the strains varied significantly in yield, the distribution varied only from two times the standard error of a difference below to three times the standard error of a difference above the mean. More than one-half of the strains did not yield significantly different from the mean. The rather high standard error of the mean (approximately 10%) probably was due to the small plot size. The strains ranged in yield from 3.72 to 8.21 tons per acre on a green basis.

The distribution of the 76 clonal lines of Parkland brome grass also shown in Table 1 indicates wide differences in pigment concentration and a somewhat similar distribution for yield as in the case of Parkland brome grass. Because of a larger standard error, the range in distribution of lines analyzed for pigments was not as great as for Fairway crested wheat grass. The larger pigment analysis error may have been due to lodging among the clonal lines, making the selection of uniform analysis samples in the field more difficult. The range in

TABLE 1.—*Frequency distribution of clonal lines of Fairway crested wheat grass and Parkland brome grass analyzed for percentage total chlorophyll, total carotenoid pigments, Beta carotene, and yield in tons per acre compared with the means for their respective populations.*

Characters studied	No. of lines below mean: Standard error of difference times 5+	4	3	2	1	No. equal	No. of lines above mean: Standard error of difference times 1	2	3	4	5+	Mean	Standard error	Range
Fairway Crested Wheat Grass														
% total carotenoids	0	2	10	9	4	9	2	6	8	0	5	20.0×10^{-4}	1.05	13.1–32.0
% beta carotene	3	5	4	8	3	11	6	1	3	4	7	6.3×10^{-4}	0.33	3.8–10.5
% total chlorophyll	0	3	5	5	8	16	8	4	2	2	2	1.30×10^{-2}	0.05	0.93–1.88
Tons per acre (green)	0	0	0	4	12	30	5	2	2	0	0	5.69	0.53	3.72–8.21
Parkland Brome Grass														
% total carotenoids	0	0	4	10	16	23	8	13	1	1	0	18.8×10^{-4}	1.64	10.2–30.3
% beta carotene	0	0	0	11	16	24	8	8	4	3	2	6.2×10^{-4}	0.65	3.4–12.4
% total chlorophyll	1	1	3	5	11	38	13	2	1	0	1	1.38×10^{-2}	0.13	0.54–2.11
Tons per acre (green)	0	0	0	2	12	52	5	4	1	0	0	7.73	0.79	5.26–12.02

pigment concentration among the strains of *Bromus*, however, was as great or greater than for Fairway crested wheat grass, varying from 10.2×10^{-4} to $30.3 \times 10^{-4}\%$ of total carotenoids; 3.4×10^{-4} to $12.4 \times 10^{-4}\%$ of beta carotene; and 0.54×10^{-2} to $2.11 \times 10^{-2}\%$ of total chlorophyll, while the range in yield was from 5.26 to 12.02 tons per acre.

CORRELATION BETWEEN PIGMENTS AND BETWEEN PIGMENT CONCENTRATION AND YIELD

Since previous results reported on the relation between pigment concentration and yield were made with ear corn, it seemed desirable to extend these studies to include forage grasses where the yield of the entire plant was included. The correlation coefficients given in Table 2 between yield in green tons per acre and concentration of total chlorophyll and beta carotene show essentially the same relationship as found with corn and indicate that pigment concentration appears to have no real relationship to yielding ability in either of the two grasses. The significant positive correlation between total chlorophyll and either total carotenoids or beta carotene is in agreement with results previously published (4) from analysis of corn leaf tissue. On the basis of these results, the selection of darker green strains of grasses should be a fair criterion for selecting superior strains in respect to carotenoid pigments.

TABLE 2.—*Relation between total chlorophyll, total carotenoids, and beta carotene concentration to yield per acre and between chlorophyll and carotenoid pigment concentration in crested wheat grass and Parkland brome grass.*

Characters correlated	Crested wheat	Parkland brome
% total chlorophyll and yield in tons per acre	-0.0189	0.0057
% total chlorophyll and % total carotenoids	0.5655	0.6339
% total chlorophyll and % beta carotene	0.4289	0.5481
% beta carotene and yield in tons per acre	0.1428	-0.0417
Level of significance, 5% point	0.2732	0.2319

DISCUSSION

From the data presented in Tables 1 and 2 it is evident that a wide range in variability in pigment concentration may be found among individual plants in commercial strains of the two grasses studied. The importance of this variability from a plant selection standpoint in forage improvement is of particular significance in its relation to vitamin A. The improvement of grasses in nutritive value should be an important phase of any forage improvement program.

The consistent lack of significant relationship between chlorophyll concentration and yield in all studies conducted at Minnesota would indicate that under natural field conditions the amount of chlorophyll present in leaf tissue is more than adequate for normal photosynthetic processes and that among strains of crop plants other factors, genetic or physiological, are of greater importance in modifying yielding

ability. The high correlation between total chlorophyll and carotenoid pigments has been consistent in all previous work. At present, no explanation can be offered for these findings save that apparently in an indirect manner the yellow pigments are effective in or by photosynthesis.

In the methods of sampling and analysis employed in this study certain sources of error have been encountered. As previously stated, the dry matter determinations were not made on the sample analyzed but on an equivalent sample. In the majority of cases, the differences in amount of dry matter between duplicate plots were less than 2%, but in some instances the differences were as great as 7%. These differences may have been due to a tendency for ice crystals to form on the sides of the glass vial during storage. The dry matter percentage applied to the sample analyzed may not have been strictly correct. Since the variability between strains was very large, this factor probably did not modify greatly the final results.

Previous studies by Miller and Johnson (4) suggested that enzymatic reactions during storage at $-15°$ C were insignificant in influencing the plant pigment concentration. Recent investigations by McKinney (2) and Barnes, *et al.* (1) suggest the advisability of inactivation of enzymes by heat before the samples are stored.

In this study the authors have favored the methods consistently giving the highest values, especially in the extraction, fractionation, and analyses of beta carotene. For a detailed review of the possible sources of error in studies of this type, the reader should consult Strain (8) and Miller (5).

SUMMARY

In a study of 55 clonal lines of Fairway crested wheat grass and 76 clonal lines of Parkland brome grass, widely significant differences were obtained in percentage of total carotenoid pigments, beta carotene, and total chlorophyll. The strains studied varied significantly in yield on a green weight basis.

No significant relationship was found between the concentation of chlorophyll or carotenoid pigments and yielding ability.

Significant correlations were obtained between the concentration of total chlorophyll and either total carotenoids or beta carotene.

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THE USE OF MODERN STATISTICAL METHODS IN FIELD EXPERIMENTS[1]

S. C. SALMON[2]

IN considering statistical methods for interpreting the results of field experiments, all, no doubt, will agree that in order to be useful, these methods must not only be sound in themselves but also that they be soundly applied; specifically that the assumptions on which they are based be valid. It seems clear that in many cases the assumptions underlying such usage in the past were not valid, and furthermore, that some of those underlying a similar use at the present time are at least questionable. The primary purpose of the present paper is to indicate the need for critical consideration of the assumptions involved whenever modern statistical methods are used in interpreting the results of field experiments.

The subject matter of this paper can be epitomized by a statement a former teacher of biometry often repeated to his classes. The statement was about as follows: "The statistical method is nothing but common sense expressed in the most beautiful language." There was at least one member of the class who did not understand the language very well. Others were more impressed and intrigued by its beauty and its elegance than with the thoughts it was intended to convey, and probably many failed to realize a very important implication, namely, that if the statistical method is nothing but common sense expressed in a different language, then deductions based on statistical interpretations and those based on common sense ought to agree. Furthermore, if they do not agree, something is wrong with either the statistics or the common sense.

It should not be inferred that when there is disagreement the statistical method or its application is always at fault. Such is believed often to be the case and that viewpoint will be stressed not because it is the only one worthy of emphasis but because it has received, it seems, too little attention. It should be noted, however, in passing, that common sense in itself is not a sufficiently reliable guide to what is true and correct. Too often it serves only as a cloak or a blind for ignorance, prejudice, and preconceived opinions. In fact, one of the greatest advantages that may be claimed for the statistical method is that it aids in arriving at truly objective interpretations. Perhaps it is sufficient for the present to be reminded that it was prejudice supported by common sense that would have sent Galileo to the stake had he not recanted, led Lavoisier to the guillotine in the French Revolution, would have stopped Pasteur's work with anthrax and rabies, and would have sent Harvey to an insane asylum had it prevailed.

Moreover, let no one assume it is only the ignorant and the uninformed who are swayed by prejudice. Probably no one so frequently

[1]Contribution from the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture, also presented as part of a symposium on "The Use of Statistical Methods" at the annual meeting of the Society in New Orleans, La., November 22, 1939. Received for publication February 23, 1940.

[2]Principal Agronomist.

and contemptuously ridiculed Pasteur as did Liebig, and certainly no one opposed him so strenuously as did the physicians of Paris. But this is no occasion for a discussion of the limitations of common sense. What should be emphasized is that we should be most careful that our adherence to common sense does not prejudice our opinions and discourage the use of any tool, statistical or otherwise, that may be found useful in interpreting experimental results.

Perhaps the need for care in applying statistical methods can be emphasized best by presenting a bit of history relating to their use in interpreting field experiments, cite a few examples, and suggest some of the precautions that should be observed.

The use of modern statistical methods for field experiments in this country began soon after the publication of Wood and Stratton's (8)[3] paper in 1910 in which they discussed some of the fundamentals of the probable error (or standard error) concept and showed how it could be used in the interpretation of experimental data. One important result of this paper, and others which followed soon after, was the substitution of replicated experiments for single plot experiments which previously had generally been used, especially for variety and similar tests. The duplication or replication of plots was not then a new idea, and in fact had occasionally been used by agronomists at least 20 or 25 years previous to that time. What this concept did perhaps more than anything else was to rationalize the principle of plot replication, and impress upon agronomists the need for consideration of random errors in field experiments. These early papers also accomplished an important result in putting a tool into the hands of the agronomist by which he could measure the random variation in experimental fields and compare more precisely the suitability of different fields for experimental work; also by means of which he could more accurately evaluate the results of experiments repeated a large number of times as, for example, cooperative experiments with farmers.

This tool also has been useful in comparing the effect on variability of different methods of preparing the ground, sequence of crops, methods of decreasing variability by uniform cropping, leveling land, etc., preliminary to the laying out of experiments. Statistical tools have been of great value in reducing and summarizing large volumes of data so they may be visualized by the investigator. They have been equally important in condensing and summarizing data for publication. While it is difficult to cite any figures to show the net result of using statistical methods in these various ways, it can hardly be doubted that in the aggregate they have been very important.

It was soon after the appearance of Wood and Stratton's paper that we first began using probable errors and standard errors to evaluate experiments; and it was then it seems that our troubles began. One of the first attempts made use of the abbreviated formula for the standard error of a difference, which states that it is equal to the square root of the sum of the squares of the respective standard errors. It was not until nearly 15 years later that agronomists learned that this formula is incorrect for many field data since it assumes no

[3]Figures in parenthesis refer to "Literature Cited", p. 319.

correlation between the variables being compared, whereas obviously in many cases the correlation is very important. The difficulty, of course, lay in the use of the abbreviated instead of the complete formula, including the correlation term.

It was about this time, also, that it was realized that errors calculated from two or three plots did not mean very much, and consequently the practice developed of pooling data in order to obtain a more accurate estimate of error. This method, of course, is still used, and within limits and with suitable precautions is a perfectly valid and useful procedure. It was assumed, however, that it was necessary to express errors as a percentage of the mean before they could be pooled, an assumption which, as we now know, was decidedly wrong in most cases though not always so. But strangely enough, when analysis of variance entered the picture, some 15 years ago, a directly contrary assumption was made, namely, that errors are independent of the mean values being determined, and it was not until Cochran's (1) paper appeared last year that it was generally admitted and became widely known that such frequently is not the case.

The coefficient of variability has not only been used as indicated above, but has sometimes been referred to as "the best measure of variability"; when, as a matter of fact, it is nothing more nor less than a measure of relative variability and may be and often is a very poor measure of variability as such. It seems to have taken a long time to discover this fact, though it should have been obvious from the very nature of the coefficient of variability itself.

Another erroneous application of the statistical method, which fortunately has not been made very frequently but is nevertheless worthy of mention, is the use of the formula for the standard error of a grand average which is given as equal to $\frac{1}{N}\times$ the square root of the sum of the squared errors of the respective averages. This formula, of course, is perfectly valid when the individual averages and the errors of those averages belong to the same statistical population. The difficulty is that it has been used without any regard to this limitation.

Additional examples could be given, but it would seem more useful at this point to consider just why it is that these errors, misconceptions, or failure to consider limitations have arisen. The reason appears to be simple. On the one hand, few agronomists had had any training in statistics, or professed any knowledge of the fundamentals of the statistical method. They were, in fact, encouraged to believe that it was not necessary to have more than a superficial knowledge of statistics in order to use them satisfactorily. They were told frequently, and in no uncertain terms by what appeared to be the best of authority, that statistical methods were necessary; that unless these methods are used their experiments, to cite a few of the phrases from the literature of the past 15 or 20 years, are "inadequate, and as likely as not to lead to incorrect conclusions," not only "not worthy of serious consideration but may be a veritable detriment to practical agriculture and discreditable to agronomic science," that "they are of little significance," and that they are not "worth what they cost,"

etc. Naturally, agronomists were somewhat concerned. Some perhaps were a bit frightened. Most of us were impressed by the complicated formulae we did not understand, by the authority of mathematics, the most exact of the sciences, and perhaps most of all by the complacent assurance of the proponents of the new methods. These, like an opiate, dulled our critical sense and gave us a feeling of confidence which though spurious was very comforting, especially when as was often the case they supported conclusions we hoped were true or which had been arrived at by other means.

We were not aware that statistics is a complex subject, that various assumptions are involved in all statistical formulae, and that the soundness of any conclusions that are reached depend quite as much upon these assumptions as on the correctness of the formulae themselves. Furthermore, the various assumptions, if stated at all, were often in language ambiguous to the agronomist and seldom if ever emphasized.

No attempt will be made to discuss the matter from the statistician's point of view. However, it is no adverse criticism and a fact that he perhaps will be the first to admit that, generally speaking, few statisticians have been familiar with agronomic problems or agronomic technic. He is excusable if he did not know that agronomy also is a complex subject and that the inter-relations between plants, on the one hand, and the soil, climate, weather, the hundreds of diseases, including many races, weeds, insects, etc., on the other, are anything but simple.

Perhaps it never occurred to him that the formulae he so carefully checked in his study or laboratory involved assumptions not always realized in an experimental field. To cite a single example, it is not strange that both agronomists and statisticians have failed to note that chi-square for independence is not a satisfactory tool for determining whether differences in bunt infection of different selections of wheat are statistically significant though a most useful one for other problems that appear to be identical, such, for example, as differences in percentages of plants having red grain from a cross involving white-grained and red-grained parents. It is easily overlooked that in the former case one is dealing with heterogeneous populations and in the latter with homogeneous populations for the reason that bunt infection is greatly affected by variation in soil, whereas red grain color is affected very little if at all.

But most of us perhaps are more interested in the present and future than in the past. One might suppose in view of the very great interest in the subject, the voluminous literature, including several books, and the nearly 30 years' experience in using statistical methods, that the difficulties of the past are behind us and that we might confidently proceed with the use of currently recommended methods. Let us hope that this is the case, though it appears that such would be an optimistic appraisal of the situation.

Current recommendations seem to imply that the statistical method should be considered not merely as a tool to be used by the agronomist if and when occasion demands, but rather as a method of research complete in itself. A sort of super-science, if you please, that deter-

mines the design of experiments and directs the interpretation of experimental data. Indeed, so far as field experiments are concerned, instead of being told, as we once were, that statistical methods are indispensable, it now seems to be the common opinion that they are not applicable at all to most field experiments of the present day, because the latter are not properly laid out. What must be done is to set up entirely new experiments designed in the light of approved statistical methods, so that these latter may properly be applied and results secured that will be dependable beyond a possible shadow of doubt. Specifically, the plots must be arranged at random, and they must be replicated sufficiently so that unquestionably valid estimates of error may be derived. A recent writer in discussing varietal trials at several stations in a state over a period of years goes so far as to say "it is only when the number of stations and years can be considered an adequate sample of all possible places and years, that worth-while predictions can be made for all places in the state and for future years." Another implies that stations in a state as well as plots in a field must be selected at random if reliable conclusions are to be expected. Unfortunately, neither author tells us how such tests, numerous as they must be, are to be financed and managed. Nor do they tell us how many seasons or places are necessary for an adequate sample, nor how it has been possible for agronomists to have made any progress in the past considering that these methods have not been used.

It may safely be assumed that most agronomists would hope to be the last to discourage the use of any methods likely to lead to better and more efficient experimentation. On the contrary, they would prefer to be among the first to encourage such use.

There are, however, a number of circumstances that suggest a certain degree of caution before accepting many of the current recommendations in their entirety. We should know what evidence there is in support of these new concepts and new methods. What assumptions are involved and have they been shown to be valid? Are they stated in terms so that agronomists as well as statisticians may have an opportunity to pass judgment upon them? It would appear that agronomists have not merely a right to a convincing and intelligible answer to these questions, but rather an obligation to themselves and to the public which they serve to satisfy themselves that the answers are correct and reliable before they embark too far from the shore of proved methods.

Let us consider pseudo-factorial designs. These were first proposed about 3 years ago and are claimed to be especially efficient for testing a large number of varieties. So far as one may judge from the literature, the validity of the method of making corrections in yields or adjusting yields, a necessary step in interpreting the data, has scarcely been considered. Agronomists have had much experience, some at least unfavorable, in correcting or adjusting yields, and may well think twice before they generally adopt any arbitrary correction method without convincing evidence in its favor. Weiss and Cox (7), in a recent paper, indicate that some limitations are involved for they specifically state it is "unwise to employ this type of design when

comparing varieties which have an extremely large range in yields." Now every agronomist knows that in most tests involving a large number of varieties some are almost certain to be found that differ widely in yield; indeed, the primary purpose of most variety tests involving large numbers is to identify such varieties.

These authors indicate that the method is unsatisfactory for such tests because of the partial confounding of varietal differences with block effects. This, of course, is true whether differences between varieties are large or small. The error introduced in making yield adjustments is likewise small when yield differences are small, but has it not been overlooked that such errors become relatively more important as the need for detecting small differences increases? It seems altogether likely that, when all of the assumptions involved in pseudo-factorial experiments are realized and accounted for, much of the supposed gain in efficiency will be found to have disappeared.

Another point on which agronomists will want a convincing answer is whether interaction is a valid measure of significant differences. Most writers who have treated the subject, and these include Fisher (2), Summerby (6), Goulden (3), and Leonard and Clark (4), definitely recommend such usage with little or no specific qualifications, or infer by examples and discussion that it may be so used with impunity. Snedecor (5), on the contrary, specifically states that it is not always a valid estimate of error, although one might infer from his discussion that such is not often the case. Also, he implies that a determination of whether it is or is not a valid estimate is not difficult though he gives no clear-cut method of doing so. These citations, together with instances in the literature of uncritical usage of interaction variance as a measure of error, would seem to indicate that the conditions determining its proper use are not well understood. It is not the purpose of this paper to show how, where, or when interaction may be used, but rather to emphasize the need for critical consideration.

For this purpose two similar, hypothetical examples and two making use of actual experimental data are presented. In the first example we will suppose a variety test is conducted both on bottom land and on upland on the same farm. The individual plot yields, the average yields, the analysis of variance, standard errors, interaction, etc., are given in Table 1.

The difference in yield in Table 1, it will be noted, is in favor of variety A in both cases and on bottom land is highly significant. On upland the difference is about equal to the standard error. The practical recommendations based on this test obviously would be that variety A should be grown on bottom land, whereas on upland it would make no material difference.

Suppose, however, that our hypothetical owner insists on growing one variety only on his farm. Must we tell him, as would be necessary if we accepted what appears to be the current opinion, that no recommendation can be made merely because the variety variance is not significantly greater than variety $\times$ field interaction variance? There can be no doubt, it seems, that such an interpretation would be grossly misleading.

TABLE 1.—*Hypothetical yields of two varieties (A and B) on upland and on bottom land on the same farm with a random arrangement of the plots.*

Plot No.	Bottom land		Upland	
	Variety A	Variety B	Variety A	Variety B
1	29	16	13	9
2	30	14	9	10
3	31	12	11	11
Average	30	14	11	10
Difference	+16		+1	

Analysis of Variance

Source of variations	df	Sum of squares		Mean square	σ
Total	11		802.25		
Varieties	1	216.75		216.75	
Fields	1	396.75			
Varieties×fields	1	168.75		168.75	
		782.25	782.25		
Error	8		20.00	2.50	1.58

Example 2 (Table 2) portrays a similar situation in which, however, variety A yields better than B on bottom land as before but less on upland, the differences in both cases being significant; on the bottom land highly significant. Again, the owner insists on growing a single variety. The common sense recomendation to be made would depend on the relative proportions of bottom land and upland. If equal proportions of each, then variety A would be expected to give the largest average yield per acre for the entire acreage. Again it would appear that basing an interpretation on the ratio of variety variance to interaction variance would lead to entirely erroneous conclusions.

The third example deals with actual experimental data, *viz.*, the differences in annual yields between Thatcher and Marquis spring wheat for each of eight experiment stations in the stem-rust area of western Minnesota and the eastern Dakotas. The average gains, the standard error of these gains, and the t values are given in Table 3. The data are summarized for two periods, one up to and including 1935, for it was at about the end of 1935 that the value of Thatcher was first generally recognized and when it was first recommended for the entire area in question. The other summary is for the full period of testing up to and including 1938. The standard errors for each station were calculated by the so-called "Student's method" which, as is now well known, is in this case equivalent to variety × season interaction in an analysis of variance. It is apparent that if varietal differences had been interpreted in terms of variety × season interaction, there is only one station (Crookston) at which the data at the end of 1935 would have supported a recommendation in favor of Thatcher. Analysis of variance for the two varieties at the four

TABLE 2.—*Hypothetical yields of two varieties (A and B) on upland and on bottom land on the same farm with a random arrangement of the plots.*

Plot No.	Bottom land		Upland	
	Variety A	Variety B	Variety A	Variety B
1	29	16	9	16
2	30	14	10	12
3	31	12	11	14
Average	30	14	10	14
Difference	+16		−4	

Analysis of Variance

Source of variations	df	Sum of squared deviations		Mean square	σ
Total	11		728		
Varieties	1	108		108	
Fields	1	300			
Varieties × fields	1	300		300	
		708	708		
Error	8		20	2.50	1.58

TABLE 3.—*Yearly gains (+) and losses (−) in yield of Thatcher as compared with Marquis at indicated experiment stations.**

Year	St. Paul, Minn.	Crookston, Minn.	Waseca, Minn.	Morris, Minn.	Fargo, N. D.	Langdon, N. D.	Mandan, N. D.	Brookings, S. D.
1929	− 3.2	12.6	− 2.2	5.2	——	——	——	——
1930	4.6	1.4	1.8	4.4	1.2	20.8	1.5	4.9
1931	0.7	6.3	2.7	5.6	2.9	4.4	− 0.7	0.8
1932	4.9	1.4	− 3.7	− 4.8	1.0	− 0.2	4.2	− 1.5
1933	3.1	1.4	1.2	——	1.0	− 4.0	——	——
1934	− 0.4	5.2	− 2.8	1.7	−0.6	0.4	1.1	0.8
1935	21.4	17.0	21.4	29.6	19.9	16.9	16.5	20.7
1936	1.0	2.6	1.9	−0.1	3.8	−0.5	——	11.6
1937	3.9	13.3	27.4	6.2	18.1	9.7	8.6	16.2
1938	17.3	18.5	16.1	18.5	12.9	17.6	9.9	9.8
Average, 1929–35	4.4	6.5	2.6	7.0	4.2	6.4	4.5	5.1
σ_d	3.0	2.3	3.3	4.8	3.2	4.1	3.1	4.0
t	1.5	2.8	0.8	1.5	1.3	1.6	1.4	1.3
Average, 1929–38	5.3	8.0	6.4	7.4	6.7	7.8	5.9	7.9
σ_d	2.5	2.1	3.5	3.5	2.7	3.1	2.3	2.8
t	2.2	3.7	1.8	2.1	2.5	2.5	2.5	2.8

*Data secured in cooperation with the agricultural experiment stations of Minnesota, North Dakota, and South Dakota.

Minnesota stations (at which plots were arranged at random) is given in Table 4 for such use as the reader may desire to make of it.

TABLE 4.—*Analysis of variance for Thatcher and Marquis at St. Paul, Crookston, Waseca, and Morris, Minn., 1929 to 1935.*

Source of variation	d/f	Sum of squares	Mean square
Blocks	54	664.73	—
Stations	3	719.27	—
Years	6	4123.87	—
Varieties	1	1017.00	1017.00*
Stations × years	18	3361.68	—
Varieties × years	6	2190.91	365.15†
Varieties × stations	3	109.56	36.52‡
Error	70	796.16	11.37
Total	161	12983.18	

*Highly significant in relation to error variance but not significant in relation to variety × year interaction variance.
†Highly significant in relation to error variance.
‡Significant in relation to error variance.

Probably no one would insist that agronomists make no mistakes nor that Thatcher is beyond all doubts superior to Marquis for all conditions likely to be encountered in this area. On the other hand, an estimated 15,000,000 acres of Thatcher wheat, representing about 90% of the acreage devoted to hard spring wheat in the stem-rust area of Canada and the United States in 1939, must be regarded as substantial evidence that they were not wrong.

Why does the use of interaction in these examples lead to erroneous interpretations? Again it seems clearly a case of making assumptions that are not valid. Thus we tacitly assume a homogeneous population. But is it not true that the mere fact that interaction is proved to be present is in itself proof that we have a heterogeneous population and have no warrant whatever for considering it is anything else? Thus, in the first two examples, we have one population of upland fields and another of bottom land fields; not a single homogeneous population of fields as the use of interaction variance implies. Similarly, in the Marquis-Thatcher comparison, we have one population of rust years and another of non-rust years, not a single homogeneous population of all years.

Attention may now be directed to a fourth example in which the use of interaction variance supports conclusions in accord with common sense interpretations, but which illustrates (as does also the Thatcher-Marquis comparison) another important point in agronomic experimentation, *viz.*, the difficulties in properly evaluating year-to-year variations. This example consists of the average differences in yield between Kanred and Turkey winter wheat at the Kansas Experiment Station, Manhattan, Kansas, for a period of 28 years. Table 5 gives the mean difference for the first half and for the last half of the period separately; also the standard errors (calculated by Student's method) and the t values. For the first 14 years the average difference is 3.0 bushels per acre and highly significant; for the last 14 years only 0.8 bushel and far below the level of statistical significance. In other words, these data for the first 14 years whether interpreted statistically or otherwise afforded no reliable basis for predicting relative yields in the second 14-year period.

TABLE 5.—*Yearly gains (+) or losses (−) in yield of Kanred as compared with Turkey at the Kansas Agricultural Experiment Station.**

Year	Gain (+) or loss (−) of Kanred over Turkey	Year	Gain (+) or loss (−) of Kanred over Turkey
1911	3.5	1925	4.5
1912	6.6	1926	1.6
1913	3.5	1927	3.1
1914	− 0.9	1928	1.7
1915	3.0	1929	2.0
1916	11.4	1930	1.3
1917	3.5	1931	+1.1
1918	5.4	1932	−1.4
1919	−0.2	1933	−3.6
1920	1.9	1934	−1.3
1921	2.3	1935	−1.0
1922	0.0	1936	1.4
1923	0.2	1937	1.7
1924	1.2	1938	2.9
Average......	3.0	Average.....	1.0
σ_d	0.87	σ_d	0.57
t	3.45†	t	1.76‡

*Data secured in cooperation with the Kansas Agricultural Experiment Station.
†Highly significant.
‡Not statistically significant.

The Thatcher-Marquis and the Kanred-Turkey comparisons are not isolated examples; they merely illustrate a fact well known to agronomists that yearly variations not only in absolute yields but also in relative yields are the general rule and constitute a principal problem in evaluating experimental results. To what extent and how statistical methods can be used in solving this problem is of great interest and importance to agronomists. Certainly we can have little confidence in a method which fails us in a critical situation even though it may not be misleading at other times.

The above, of course, does not mean there is no place for statistical analysis even though there may be serious limitations with respect to their use in interpreting year-to-year variations. As a matter of fact, they were useful in evaluating Thatcher and Marquis, especially in proving clearly that the difference in yield could not reasonably be explained by the plot-to-plot variation within each experimental field. They would be useful in showing that interaction is statistically significant if there is any doubt on this point. A statistical study of the Kanred-Turkey comparison year by year would no doubt be useful in determining in which years differences in yield were significant.

One might, if so disposed, follow the recommendations of a recent writer in which he stated that if in comparing two varieties it is known that one is always better than the other, we are justified in considering only one-half of the frequency curve, thereby doubling the probability, and with respect to Marquis and Thatcher show a significant difference in favor of Thatcher at the end of 1935 at all stations but one. It is a bit difficult, however, to see just what is learned by using a statistical analysis to prove that one variety is better than another when as a basis for our calculations we set up the assumption that it is better.

In concluding this portion of the discussion, it should be noted that the difficulties in using statistical methods are by no means universally ignored or overlooked. Two recent papers, in particular, by Cochran (1) and by Yates and Cochran (9), give extensive discussions of precautions that should be observed. Others might be mentioned. Perhaps they suggest a somewhat different trend in our thinking such that we may in the future expect as critical a consideration of statistical methods as we have in the past of the experiments to which they are to be applied. If so, we may confidently expect better statistical treatment of data and better interpretation of field experiments.

Be this as it may, it would seem that a correct and complete evaluation of statistical methods is not likely to be achieved until they are considered in relation to the broad objectives and methods of research that generally prevail. In agronomy there seem to be two schools of thought indicated not so much by expressed opinions or stated philosophies as by the manner in which problems are attacked. Thus we have one school which seems to be concerned only or primarily with immediately practical objectives, and little if at all with determination of principles or general relations. This school emphasizes the need of empirical trials on as extensive a scale as time and money permit, and for all conditions where it is anticipated the results will be applied. If funds were available, such persons presumably would have variety trials, fertilizer experiments, soil, culture, and rotation tests, etc., repeated a number of times in every county in the United States where such problems were thought to exist. Data derived from such experiments, if the plots were arranged at random, presumably would be considered ideal for statistical treatment. Research, taken as a whole, has been so thoroughly worth while that such experiments, though expensive, would no doubt be worth all they cost, but it may seriously be questioned whether they would constitute a wise expenditure of public funds.

Science, in general, has made most progress in quite a different way, and it is difficult to believe that agronomy is so different that the same methods are not applicable. Important discoveries have been made by empirical trials, it is true, but in general science has used this method as a last resort and not by preference. The more general approach has had as a fundamental objective the determination of cause and effect relations so that predictions might be made not so much on the basis of statistical calculations as from established principles carefully verified.

This does not in any way preclude extensive experiments; on the contrary a certain number of experiments conducted throughout a wide range of conditions are necessary in order to establish principles on a sound basis. Neither does it preclude statistical analysis of data. On the contrary, again, such may be even more necessary and valuable than in the former case. The point is that in the scientific method of attack statistical methods assume their proper role as tools to be used if and when they are needed and suitable for the purpose. They may not be needed at all; for some purposes and occasions they may be indispensable.

Thus with respect to the Marquis-Thatcher comparison, we believe Thatcher is a superior variety simply because, as a result of nearly 75 years' experience in growing spring wheat and numerous greenhouse, laboratory, and field experiments and observations, we know (a) that stem rust is a very important factor in limiting yields; (b) that Thatcher is highly resistant to stem rust, that Marquis is susceptible, and that the former yields relatively much more when stem rust prevails; and (c) that in non-rust years Thatcher yields substantially the same as Marquis. Granting these facts, it requires no fine-spun logic to reach the conclusion that Thatcher rather than Marquis should be grown. Statistical methods were not necessary to demonstrate the importance of stem rust nor to prove that Thatcher is more resistant to stem rust than is Marquis. They were useful in determining whether yields were substantially different in non-stem-rust years. It would not be difficult to conceive of a situation where statistical methods would be very valuable if not essential, as for example, in determining whether differences in yield due to some disease having a minor effect on yield were significant. The demonstration of such a relation might be very important if the disease were widespread.

The approach by the scientific method is especially important in relation to future progress. Thus we know that Thatcher is susceptible to leaf rust. It is possible that wide distribution of a susceptible variety may so favor the spread of leaf rust that much of the advantage of growing Thatcher may be nullified. Fortunately, and thanks to the scientific method, this problem has been anticipated and as a result there are now being tested literally thousands of selections and varieties that are resistant not only to stem rust, but also to leaf rust and to other diseases known to be important factors in determining yields.

Also it was discovered many years ago that Kanred winter wheat is now susceptible to the prevailing races of leaf rust though resistant to the races that were common when it was first grown. Probably much of the difference in response in the two 14-year periods is related to these facts. Here again the knowledge of the causal relations suggested the remedy and as a result varieties are now being grown that are resistant to leaf rust. We are no longer greatly concerned, from a strictly practical point of view, as to whether Thatcher is superior to Marquis or Kanred to Turkey. Our real anxiety is whether the numerous new varieties that have been developed in recent years are superior. In settling these questions, statistical methods will without doubt be used in so far as they can contribute to sound and reliable conclusions.

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NOTE

GERMINATION OF SEED OF GOOSEGRASS, *ELEUSINE INDICA*

DURING the last several years we have carried on work on the germination requirements of various weed seeds. Although the work with goosegrass, *Eleusine indica* (L) Gaertn., involved approximately 140 tests of 100 seeds each with three samples collected in successive years, it is not considered that the problem is completed. Since probably it will be impossible for the authors to complete this work, a summary of the results obtained is given in the hope it may serve as a starting point for others.

Germination was negligible at 10°, 15°, and 20° C, constant temperature, and at 15° to 25° alternating temperature.[1] When 0.2% solution of potassium nitrate was used to moisten the substratum, germination of fresh seed was 90% or above after 14 to 56 days in the germinator at the alternations 20° to 35°, 20° to 40°, or 25° to 40°. Germination at the alternating temperature 20° to 30° with light, was slower and with two of the three samples less complete. When tested with water, germination was poor at 20° to 30°. At the higher temperatures germination with water was slower than with potassium nitrate and often the final germination with water was lower (Table 1).

Seed tested approximately 2 months after collection showed the same response to temperature as when freshly harvested.

Total exclusion of light had little effect on germination when potassium nitrate was used but caused a reduction in germination when water was used to moisten the substratum.

Prechilling the seed at 3° C for 2 to 8 weeks was not beneficial.

Scarification with emery paper caused earlier germination but even after scarification (the pericarp is thin and papery so that it is the true seed coat that is affected) germination was benefitted by potassium nitrate and high temperature.

In conclusion, 20° to 35° C or 25° to 40° C alternations seem to be the most favorable temperatures for germination. Potassium nitrate is beneficial and light is needed if potassium nitrate is not used. The time for complete germination at 20° to 35° C with potassium nitrate

[1]For all alternating temperature conditions, the seed was kept for approximately 17 hours at the first temperature mentioned and for 7 hours at the second temperature.

TABLE 1.—*Germination of freshly harvested seed of Eleusine indica at four temperature alternations, averages of duplicate tests of 100 seeds each.*

Sample No.	Percentage germination in 14 days at temperature alternation indicated				Percentage germination in 56 days at temperature alternation indicated			
	20°–30° C With light	20°–35° C	20°–40° C	25°–40° C	20°–30° C With light	20°–35° C	20°–40° C	25°–40° C
	Water used to moisten substratum							
440	6.0	66.0	46.5	34.0	28.5	82.0	86.5	36.5
397	7.5	68.0	60.0	95.0	16.0	92.0	91.5	95.0
Mean	6.75	67.0	53.25	64.5	22.25	87.0	89.0	65.75
	Potassium nitrate used to moisten substratum							
440	25.0	76.0	42.5	92.5	82.5	93.5	94.0	95.5
397	52.0	95.0	54.0	98.5	98.0	98.5	90.0	98.5
Mean	38.5	85.5	48.25	95.5	90.25	96.0	92.0	97.0
Means	22.62	76.25	50.75	80.0	56.25	91.5	90.5	81.37

varied from 28 to 84 days, depending upon the maturity and the age of the seed.—EBEN H. TOOLE and VIVIAN K. TOOLE, *Division of Fruit and Vegetable Crops and Diseases, U. S. Dept. of Agriculture, Beltsville, Md.*

AGRONOMIC AFFAIRS

RECEIPTS AND DISBURSEMENTS FOR MEETINGS OF THE THIRD COMMISSION OF THE INTERNATIONAL SOCIETY OF SOIL SCIENCE

THE following statement, submitted by Dr. S. A. Waksman, covers the receipts and expenditures in connection with the meetings of the Third Commission of the International Society of Soil Science held at New Brunswick, N. J., August 30 to September 1, 1939.

RECEIPTS

Contributions by outside organizations, as listed in Vol A.	$1,100.00
Contributions of the N. J. Agr. Exp. Station	100.00
Contributions of College of Agriculture, Rutgers University, to cover cost of banquet	189.75
Contribution of Soil Science Society of America (to cover bill for Vol. B)	404.00
Registration	117.00
Tickets for supper, dormitory accommodations, and miscellaneous	276.00
Sale of reprints	352.60
Sale of Volumes A and B	7.50
	$2,546.85

DISBURSEMENTS

Dormitory rent	$ 243.00	
Supper, tea, and miscellaneous	109.50	
Banquet given by Rutgers University	189.75	
Editorial work on Volumes A and B	45.00	
Printing of program	22.50	
Printing of Vol A	944.90	
Printing of Vol. B	404.00	
Cost of reprints	360.00	
Mailing charges of Volumes A and B	135.61	
Shipment of remaining Volumes to Dr. Pohlman	9.41	
Cash on hand	83.18	
		$2,546.85

SUMMER MEETING OF CORN BELT SECTION

THE summer field meeting of the Corn Belt Section of the American Society of Agronomy is scheduled for September 4, 5, and 6 at the Iowa State College, Ames, Iowa. Registration will be in the late afternoon of Wednesday, September 4, with a general meeting and group conferences in the evening. On Thursday the agronomic research work at Ames will be seen in the field with a dinner in the evening. On Friday the group will split into different parties on the basis of primary interests. Plans are underway for a grasslands conference in conjunction with the meeting, similar to that held at Wooster, Ohio, last summer.

SUMMER MEETING OF SOUTHERN SECTION

THE summer meeting of the Southern Section of the American Society of Agronomy will be held in Louisiana August 6 to 9 under the supervision of the Crops and Soils Department of the Louisiana Agricultural Experiment Station.

An automobile trip through the state is being planned for the purpose of visiting substations and experimental fields at which problems of soil fertility and fertilizers and the breeding and culture of cotton, corn, forage crops, rice, and sugarcane are being studied.

For further details communicate with Dr. Franklin L. Davis, Crops and Soils Department, Louisiana Agricultural Experiment Station, University, La.

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THE RELATIONSHIP BETWEEN LEAF AREA AND YIELD OF THE FIELD BEAN WITH A STATISTICAL STUDY OF METHODS FOR DETERMINING LEAF AREA[1]

J. F. DAVIS[2]

SINCE 1921 considerable emphasis has been given to fertility studies with reference to the field bean, but rather discouraging results have been obtained due to the inconsistency of response to the same analysis of fertilizer both during the same season and from year to year on the same soil type. However, a few remarks as to the growth habit of the bean plant in Michigan might tend to clarify these apparent discrepancies in the results obtained.

The bean-producing area is located in the central-eastern part of the Lower Peninsula, known locally as the Saginaw Valley and Thumb area. The soils in this area are predominately fertile loams and silt loams. Higher yields of beans are secured from this area than from other areas in Michigan although the soil types are very similar. This situation would indicate that factors other than soil fertility materially affect the growth and maturity of the crop.

The length of growing period of the field bean is approximately three months. The beans are planted normally about the first week in June and harvested during the first part of September. As the crop must mature in a relatively short period of time, climatic conditions play a very important part in the development of the plant. The crop is susceptible to late spring and early fall frosts and is extremely sensitive to adverse moisture conditions. At blossoming time humidity and temperature conditions appear to control the number of pods that are set. Under unfavorable temperature and moisture conditions a number of the blossoms are frequently blasted, thus resulting in a material decrease in the yield. It is frequently observed early in the season that plants on fertilized plats make considerably more vegetative growth than do plants on plats receiving no fertilizer. This difference in growth appears gradually to diminish. At the time of blossoming the difference is very small, and at harvest time the yields

[1]Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Authorized for publication by the Director as Journal Article No. 390 (n. s.) of the Michigan Agricultural Experiment Station. Received for publication December 29, 1939.

[2]Assistant in Soils. The writer is indebted to Professor W. D. Baten for assistance in the preparation of this manuscript.

from untreated plats do not differ greatly in many cases from yields of fertilized plats. The difference in early growth leads to erroneous opinions as to the actual benefit derived from the use of fertilizers due to the fact that this increase in vegetative growth is not always reflected in the yield of beans at the time of harvest. In view of these circumstances the following study was begun to obtain more information regarding the effect of fertilizer on factors other than yield.

PROCEDURE

For part of this work it was thought advisable to secure, at the beginning of the blooming period, the leaf area for a number of bean plants. These first leaf area measurements were made with a planimeter. However, this method required so much time that it was soon deemed advisable to devise some quicker method of measurement. It was believed that if the product of the length and width measurements of the leaflets were multiplied by a suitable factor the result would represent a reliable estimate of the leaf area. In 1935 the length and width measurements of 360 leaflets measured with a planimeter were taken by laying the pressed leaflet on cross section paper. The length and width measurements were expressed in 1/20 inch units, corresponding to the units on the cross section paper. The two outside leaflets of a bean leaf are irregular in form and in many cases the midrib is distinctly curved which is coincident with unequal development of the two leaflet lobes (Fig. 1). The center leaflet on the contrary, is regular in form, and due to this fact it would appear logical that a higher correlation might exist between leaflet area and length and width measurements of this leaflet than in the case of the irregularly shaped outside leaflets. Leaflet areas were predicted from the length times width of the leaflets by three different methods.

DISCUSSION

The predicting equations are presented in Table 1. First, the regression equation of area, as might be determined by the planimeter, on length times width for all the leaflets was found by the least squares method to be $A = .001475\ L \times W + .07$.[3]

TABLE 1.—*Four equations for predicting leaf or leaflet area from the length times the width of bean leaflets.*

Equation	How constants in equation were obtained
$A = .001475\ L \times W + .07$	Least squares
$A^* = .001582\ L \times W$	Average of ratios of form $\left(\frac{\text{Leaflet area}}{L \times W}\right)$ for all leaflets by least square method
$A = .001433\ L \times W$	Same as above; only center leaflets used
$A = .004517\ L \times W$	Same as above; center leaflets used; Area refers to total leaf area rather than leaflet area

*Since a bean leaflet resembles to some extent an ellipse in form, we would expect a factor calculated from the ratio of area/length times width to approximate the figure 0.7854, since the area of an ellipse is expressed by the formula $\text{Area} = 0.7854\ L \times W$. If the factor 0.001582 is multiplied by 400, we arrive at the figure 0.6328 which is comparable to the value 0.7854. It is necessary to multiply the factor expressed in the equation by 400 because the factor was calculated in 1/20 inch units corresponding to the units on the cross section paper.

[3]L and W are expressed as 1/20 inch units corresponding to the scale of the cross section paper used in taking the measurements.

A second possibly suitable factor was found by averaging the 360 ratios of the form, area/length×width. This average was .001582 and the predicting equation became A=.001582 L×W. A third factor, .001433, was similarly found by averaging the above ratios for the center leaflet only. To test these predicting equations, 50 of the 360 leaflets were selected at random and their areas as calculated by the three methods were compared with the planimeter areas.

Significant differences were found between the calculated areas and planimeter areas in the first two methods, but not in the third method where only the center leaflets were used. The mean differences, their standard errors, and "t" values are given in Table 2. In view of the fact that a very close agreement resulted between the planimeter measurements and estimated areas when the factor obtained by averaging the ratios of the form, area/length×width of the center leaflet, was used, the use of the relationship between the entire leaf area and the length× width measurement of the center leaflet should further facilitate the work in leaf area studies.

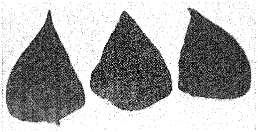

FIG. 1.—A bean leaf consists of three leaflets, the center one of which is regular in form.

TABLE 2.—*Statistical constants obtained from calculated areas of bean leaflets when compared with the area computed from the use of the planimeter.*

	Mean difference	Standard error of mean difference	"t"	"t" 5% point
A =.001475 L × W +.07	.1286	.0339	3.794	2.008
A =.001582 L × W Leaflet Area/(L × W) all leaflets	.2490	.0384	6.484	2.008
A =.001433 L × W Leaflet Area/(L × W) center leaflets	.0152	.0335	0.454	2.008
A =.004517 L × W Total leaf area/(L × W) center leaflets	.06832	.05992	1.140	1.971

In 1936, the average of 226 ratios of the form, total leaf area/length times width of the center leaflet, was found to be .004517 (Table 1). The total leaf areas found by this method agree essentially with the planimeter areas. The mean difference and its standard error and "t" value have been presented in Table 2.

The average total leaf area for the 226 leaves was found to be 6.93 square inches with an average leaflet area of 2.31 square inches. Based on these values the mean differences in Table 2 calculated from factors (0.06832 square inch and 0.0152 square inch) represent 0.98% and 0.66%, respectively, of the average leaf and leaflet area, which is a very low percentage of error.

In arriving at a suitable factor for estimating leaf area it would be desirable to know the minimum number of leaves necessary to

measure in order that a valid estimate of the factor be obtained. This minimum number will be obtained from measurements of 226 leaves as an illustration. The mean and standard deviation of the ratios, area/length$\times$width, were obtained for these 226 leaves. From this parent population or universe one may sample and find the average of the ratios and compare this average with the average of the ratios of the 226 leaves. If a small number of leaves is used in the sample, one can expect a larger deviation from the average of the ratios of the 226 leaves than when a larger number is used. The number in the sample can be obtained from Carver's formula if one assumes that the average of the ratios from the sample should lie within certain limits of the means of the parent population.[4]

The mean and standard deviation of the 226 ratios are, respectively, 0.454 and 0.065.

If one assumes that the mean of the ratios from the sample should lie within 0.01 of the mean on the average about 68 times in 100, the number is obtained from the formula due to Carver:

$$\sigma_z = \sqrt{\frac{S-N}{N\ (S-1)}}\ .\sigma_{\text{parent}},$$

where S is the number in the parent, N is the number in the sample, and σ_z is the standard deviation of the distribution made up of all possible sample averages. According to this formula and the accepted limits $N \geq 36$ leaves.

$$\sigma_z = \sqrt{\frac{226-N}{N\ (S-1)}}\ .065 = .01$$

To check whether or not theory is in keeping with practice in sampling, two samples of 45 leaves and one of 25 leaves were taken from the 226. The means from the samples of 45 were within the limits taken in finding N; the mean of the ratios from the 25 leaves was not within the limits. This suggests that for this material any sample containing 36 or more leaves will give an average within 0.01 of the mean of the 226 about 68% of the times, or since the factor for finding the area is an average of ratios, this factor within the limits suggested can be obtained from 36 or more leaves.

Since the method described appeared to be rapid enough for practical use and at the same time sufficiently accurate to give reliable measurements, bean plants were selected at the beginning of the blossoming period from plats receiving an application of 300 pounds of a 4–16–4 fertilizer and from corresponding untreated plats. Ten large plants representing as nearly as possible the average large size plants and 10 small plants representing the average small plants were selected. At the same time 20 of the large and small plants were tagged to be harvested individually at time of maturity. This work was carried out in three different fields, two of which were located in Tuscola County and one in Sanilac County. Three soil types, Brooks-

[4]CARVER, H. C. Annals of Mathematical Statistics. Vol. 1. 1930.
BATEN, W. D. The Tõhoku Mathematical Journal. Vol. 36. 1933.
RICHARDSON, C. H. Statistics of Sampling. Dissertation at University of Mich. 1936.

ton silt loam, Miami silt loam, and Napanee loam, were the soils on which the fields were located. The idea in mind was to determine whether or not any significant differences in leaf area existed between bean plants on fertilized plats and those on untreated plats, and if a difference existed whether or not this difference would be reflected in the yield of individual plants, thus giving some indication of the effect of leaf area on the yield of a bean plant. The mean leaf areas and yields with their respective standard errors were computed, together with the mean difference of leaf areas and yields of the plants from the fertilized and untreated plats. The leaf area is recorded in square inches and the yields in grams of dry beans per plant.

The data secured from the leaf area measurements are presented in Tables 3 and 4. The data show that extreme variations existed in

TABLE 3.—*Mean leaf areas of bean plants from fertilized and untreated plants.**

Soil type	Large plants		Small plants	
	Fertilized	Untreated	Fertilized	Untreated
Brookston silt loam....	451.0±24.4	439.1±46.0	165.1±12.4	158.6±11.1
Miami silt loam.......	355.5±26.4	260.1±28.7	121.4± 8.4	109.6± 9.7
Napanee silt loam.....	204.4±14.1	174.3±16.6	99.5± 6.7	64.8± 4.7

*Leaf areas expressed in square inches per plant.

TABLE 4.—*Mean differences between leaf areas of bean plants from fertilized and untreated plats.*

Size of plants	Brookston silt loam	Miami silt loam	Napanee silt loam
Large..........	11.9±52.1	95.4±39.0	30.1±21.8
Small..........	6.5±16.6	11.8±12.9	34.7± 8.2

the leaf area of plants growing on different soil types. It is not unlikely that location was also a factor in determining the leaf area of plants since each soil type was in a different location. The Brookston soil was located near Unionville, the Miami near Cass City, and the Napanee near Sandusky. It would be impossible to segregate the effects due to soil type and those due to location in this particular study. In the case of fertilized plats the large plants grown on the Brookston soil had an average leaf area of 451.0±24.4 square inches compared to 355.5±26.4 square inches for plants on the Miami soil and 204.4±14.1 square inches for plants grown on Napanee soil. The corresponding leaf areas for plants from untreated plats were 439.1±46.0, 260.1±28.7, and 174.3±16.6 square inches, respectively. The mean difference between the leaf area of large plants from the treated and untreated Miami soil was significant. Similarly the small plants from the fertilized plats had a leaf area of 165.1±12.4, 121.4±8.4, and 99.5±6.7 square inches as compared to 158.6±11.1, 109.6±9.7, and 64.8±4.7 square inches for plants from unfertilized plats on the Brookston ,Miami, and Napanee soils respectively. In these comparisons only the mean difference in leaf area of plants from treated and the untreated plats on the Napanee soil was found to be signifi-

cant. Attention should be called to the fact that in every instance the leaf area of the plants from fertilized plats was greater than the leaf area from the untreated plats. As significant differences in leaf area were obtained between the large plants from fertilized and unfertilized Miami soil and between the leaf areas of small plants on the treated and untreated Napanee soil, the results from Tables 3 and 4 would suggest that if a sufficient number of plants from each plat had been measured, significant differences might have been obtained in all cases.

As shown in Tables 5 and 6, no significant differences were found to exist between the yields of plants of corresponding size from treated and untreated plats on the different soil types. With the exception of the one case on the Brookston soil in which the yield from the fertilized plat was less than the yield from the untreated plat, all yields of plants from fertilized plats were higher indicating again that if a sufficient number of plants had been used significant difference in yield might have resulted. The data appear to indicate that there is a tendency for a positive correlation to exist between mean leaf area and mean yield and that with an increase in leaf area an increase in yield might result. However, it does not necessarily follow that correlation within plats is the same as correlation between the means for the different variables, and it would be necessary to repeat the experiment using a larger number of plants before definite conclusions could be drawn.

TABLE 5.—*Mean yields of bean plants from fertilized and untreated plats.**

Soil types	Large plants		Small plants	
	Fertilized	Untreated	Fertilized	Untreated
Brookston silt loam	22.4±1.43	20.5±1.62	9.3±1.23	9.9±0.73
Miami silt loam	23.4±2.12	19.0±2.00	9.3±1.24	6.7±0.46
Napanee silt loam	12.6±0.77	12.5±0.84	5.3±0.39	4.4±0.45

*Yields expressed in grams per plant.

TABLE 6.—*Mean differences between yields of bean plants from fertilized and untreated plats.*

Size of plants	Brookston silt loam	Miami silt loam	Napanee silt loam
Large	1.9±2.60	4.4±2.60	0.1±1.14
Small	−0.6±1.43	2.6±1.32	0.9±0.60

SUMMARY

The data presented show that a close approximation exists between leaf areas measured with a planimeter and leaf areas estimated from the use of factors obtained from length and width measurements of the center leaflets.

Total leaf area = *.004517* $L \times W$ (*of center leaflet*) is the best equation of the four because of the time saved since only the length and width of the center leaflet are necessary.

It would be possible to secure the leaf area of a bean plant without necessitating the removal of the leaves. The only measurements required would be the length and width measurements of the center leaflet.

The data show that the measurements of 36 leaves are sufficient to arrive at a suitable factor.

It seems possible that this method of securing leaf areas need not be limited to the bean plant but could be used with any plant with similar leaf habits providing a suitable factor were calculated.

In all instances, plants both large and small, from fertilized plats, had a greater average leaf area than plants from untreated plats. However, these differences were not found to be significant except in one case in the large plants and one in the small plants, but since all of the differences were in favor of the fertilized plats the results indicate a tendency for plants from fertilized plats to have greater leaf area than plants from untreated plats.

Similarly the yields of plants from the fertilized plats were greater than those from unfertilized plats with one exception, but again these differences were not great enough to be significant with the number of plants used.

In either case the indications are that if a sufficient number of plants had been used significant differences might have resulted.

With the inherent variability that is evident between individual plants the data bring out very clearly the necessity of using a number of plants sufficiently large to overcome this variability before a definite conclusion can be reached.

NATURAL SUCCESSION OF VEGETATION ON ABANDONED FARM LANDS IN TETON COUNTY, MONTANA[1]

B. IRA JUDD[2]

MUCH interest has been manifest during the past few years in the process of natural succession of vegetation on abandoned farm lands. In view of this, various investigators (1, 3, 4, 6, 7)[3] have made this process the object of careful study. This paper presents further information on natural revegetation of previously cultivated land representing a portion of the Great Plains heretofore unreported.

Time did not permit the taking of quadrat counts on the fields studied, but the vegetation of each field was checked, listing the species encountered and an attempt made to give the relative frequency of each species.

LOCATION AND DESCRIPTION OF AREA

The observations were made in August 1939 in Teton County, Montana, located in the northwestern part of the state southeast of Glacier National Park. It is bounded on the south by Sun River and on the west by the continental divide and the Sun River (Fig. 1).

The greater part of Teton County covers a transitional area between the Great Plains to the east and mountains to the west. The mountains, formed by a fault, rise abruptly and are without a distinct foothill section. Gravel-capped plateaus traversed by wide stream valleys and often eroded into flat-topped gravelly ridges extend east from the mountains for 40 miles. These plateaus have plain surfaces and slope east from elevations of 4,800 to 5,100 feet down to 4,000 to 3,900 feet. It is on these plateaus that most of the abandoned fields are located.

The climate of Teton County is semi-arid. It is influenced by the varying altitude and by mountains to the west. The area is subjected to great temperature extremes with a mean annual temperature of 42.7° F at Choteau. The mean annual precipitation at the same station is approximately 13.48 inches (Table 1). Sixty-five to 75% of the total annual rainfall is received largely in small torrential showers which cause considerable run-off in the more rolling sections. The county is subject to brisk westerly and southwesterly winds which are usually stronger during the early spring months, and in dry seasons considerable wind erosion and crop damage occurs.

In spite of the fact that observations were made during one month (August) only, it is felt that the vegetation found was representative. In the first place, little attention can be paid to the annuals since no fields abandoned one year were found. Secondly, because of the rather short growing season of 110 days (5), one would not expect a seasonal

[1]Contribution from the Department of Agriculture, Arizona State Teachers College, Tempe, Ariz. Received for publication January 29, 1940.

[2]Head of Department. Acknowledgment for constructive suggestions is made to Dr. Frederic E. Clements.

[3]Figures in parenthesis refer to "Literature Cited", p. 336.

TABLE I.—*Precipitation and temperature records by months at Choteau, Montana.*

Month	Precipitation, inches*	Temperature, °F†		
		Mean	Absolute maximum	Absolute minimum
December....	0.52	24.5°	78°	−28°
January......	0.63	20.6°	79°	−42°
February.....	0.52	22.6°	64°	−40°
March.......	0.76	21.8°	82°	−28°
April........	0.82	42.4°	85°	−9°
May.........	2.01	51.4°	92°	18°
June.........	3.01	59.5°	96°	28°
July.........	1.77	65.1°	101°	34°
August......	1.01	63.1°	98°	29°
September ...	1.16	64.4°	92°	10°
October......	0.60	44.4°	86°	−15°
November ...	0.67	33.2°	77°	−25°
Annual......	13.48	42.7°	101°	−42°

*Average for a period of 24 years, 1906–30.
†Average for a period of 40 years, 1890–1930.

variation of annuals. The perennial vegetation will not change abruptly seasonally unless some disturbance factor enters.

The soils of the areas studied were, for the most part, shallow gravelly or stony loams underlain by gravel. The soil would begin to drift after the original root fiber had been destroyed, leaving the stones more prominent (Figs. 2 and 3). The torrential nature of the rainfall coupled with the fact that 73% or 9.78 inches of the annual precipitation comes between April 1 and September 30 (5) also aggravates the erosion problem.

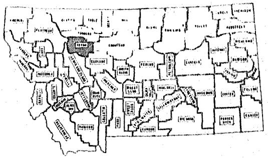

FIG. 1.—Map showing geographic location of Teton County, Montana.

Although no specific fields were found which had been abandoned one year, from observations of fields being fallowed such plants as gumweed, *Grindelia squarrosa* (Pursh.) Dunal; tumbling mustard, *Sisymbrium altissimum* L., the sunflowers, *Helianthus* spp. L.; and Russian thistle, *Salsola pestifer* A. Nels., were the most common pioneer invaders.

RESULTS

Field 2a.[4]—This field had been broken about 1930 and farmed to grain crops until 1937 when it was abandoned. Gumweed was the most conspicuous forb. There was also a good covering of small Russian thistle plants. Less common forbs were mountain sage, *Artemisia frigida* Willd., and skeleton weed, *Lygodesmia juncea*

[4]Figures in field numbers refer to number of years abandoned.

FIG. 2.—Typical surface soil conditions on an abandoned field. Stones are prominent after top soil has eroded away.

(Pursh.) D. Don. A few plants of western needlegrass, *Stipa comata* Trin. & Rupr., and green needlegrass, *Stipa viridula* Trin., were scattered throughout.

Field 4a.—This was originally broken in 1914 and farmed principally to grain crops until 1935 when it was abandoned. There was an excellent covering of weeds comprising such species as mountain sage, Russian thistle, snakeweed, *Gutierrezia sarothrae* (Pursh.) Britton & Rusby, wild rose, *Rosa* sp. (Tourn.) L., and skeleton weed. A few plants of foxtail, *Setaria viridis* (L.) Biarxv., and of western needlegrass were sparsely interspersed with the forbs.

Field 4b.—This was originally broken in 1918 and farmed to small grain crops and corn until 1935 when it was abandoned. It was covered principally by gumweed and mountain sage. In addition there were a number of snakeweed and red mallow, *Sphaeralcea coccinea* (Nutt.) Rydb., plants. Spots of green needlegrass, western needlegrass, and western wheat grass, *Agropyron smithii* Rydb., were scattered over the entire area.

Field 6a.—This field was broken in 1918 and farmed to small grain until 1933, when it was abandoned. It was covered principally with Russian thistle plants. Other forbs were red mallow, mountain sage, tumbling mustard, gumweed, and goldenrod, *Solidago* sp. L. Plants of western needlegrass and mats of western wheat grass were interspersed with the forbs. Recovery seemed to be impeded because of overgrazing.

Fields 7a and b.—These areas had both been handled rather similarly and the stage of recovery was about the same. The grasses in terms of composition were in about the same proportions as the forbs. Western needlegrass was the most common. Western wheat grass, blue grama, *Bouteloua gracilis* (H. B. K.) Lag., and June grass, *Koeleria cristata* Pers., were also found, though in lesser abundance than the western needlegrass, decreasing in the order named. The perennial forbs, such as mountain sage, snakeweed, and goldenrod and the biennial forb gumweed were more common than the annual weeds.

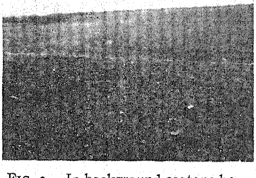

FIG. 3.—In background ecotone between native prairie, left, and abandoned field, right. Note rocks and gravel in foreground.

Field 8a.—This was broken in

1917 and farmed to small grains until 1931, when it was abandoned. There was a good covering of western needlegrass with some June grass, foxtail, western wheat grass and a few plants of blue grama and green needlegrass. The grasses were in the majority. Such forbs as mountain sage, skeleton weed, snakeweed, and cat's paws, *Antennaria compestris* Rydb., were most common.

Field 8b.—This field was originally broken in 1914 and abandoned in 1931. Because of overgrazing mountain sage was the most conspicuous type of vegetation with considerable wild roses. Other forbs were goldenrod, snakeweed, and gumweed. Although the grasses were in a minority there were a large number of species present. Blue grama, western needle, western wheat grass with some plains muhly, *Muhlenbergia cuspidata* (Torr.) Rydb., were common, the first three species being in about equal abundance.

Field 10a.—This area was originally plowed in 1927, planted to wheat, disked in 1928 and again sown to wheat, after which it was abandoned. It had a good covering of grasses including western wheat grass, western needlegrass, blue grama, and June grass. Although the grasses were in the majority, such forbs as goldenrod, mountain sage, snakeweed, canada fleabane, *Erigeron canadensis* L., and *Evolvolus* sp. L., were also found.

Field 11a.—This was broken out in 1917 and farmed principally to grain crops until 1928, when it was abandoned. The soil was gravelly. Western needlegrass was most common, with western wheat grass the second most common grass. A few plants of June grass were found. Mountain sage was the most prominent forb. Others were gumweed, snakeweed, sunflower, and red mallow. This field had been heavily overgrazed hence succession was retarded.

Field 12a.—This was broken in 1919 and farmed to grain crops until 1927, when it was abandoned. The most conspicuous forb was mountain sage, other forbs being gumweed, snakeweed, and cinquefoil, *Potentilla* sp. L. Western wheat grass and bluebunch wheat grass, *Agropyron spicatum* (Pursh.) Scribn. & Smith, were the most common grasses with some purple three-awn, *Aristida purpurea* Nutt., and bottlebrush, *Sitanion hystrix* (Nutt.) J. G. Smith, being intermixed. This area had been badly overgrazed.

Field 13a.—This area was broken in 1923, sown to oats two years followed by sweet clover, after which it was abandoned. The sweet clover had persisted and was rather common. Western wheat grass and western needlegrasses were also common. On the sandier spots sand reedgrass, *Calamovilfa longifolia* (Hook) Scribn., was found. Relatively few forbs were present.

Field 13b.—This field was broken in 1918 and farmed to grain crops until 1926, when it was abandoned. The grasses seem to be in the majority. Western needlegrass and bluebunch wheat grass were the most common with some western wheat grass, June grass, three-awn, and blue grama being present. Mountain sage and goldenrod were the most common forbs.

Field 16a.—This field was broken in 1917 and farmed to grain crops until 1923, when it was abandoned. It had a good covering of western wheat grass, bluebunch wheat grass, June grass and western needle-

grasses. Such forbs as snakeweed, mountain sage, goldenrod, blazing star, *Liatris* sp. Schreb, gumweed, and cinquefoil were common.

Field 16b.—This had a similar cover with the addition of blue grama, which was common.

Field 17a.—This was broken in 1915 and farmed to small grains until 1922, when it was abandoned. The grasses were by far in the majority with bluebunch wheat grass, western wheat grass, and western needlegrass being common. Some blue grama and muhlenbergia were also found. Cinquefoil and mountain sage were the most common forbs.

Field 17b.—This field, which had been in cultivation three years before abandonment, supported about the same type of vegetation as 17a; however, blue grama was more prevalent with the addition of some three-awn grass.

Field 18a.—This field was broken in 1917 and farmed to grain crops until 1921, when it was abandoned. There was a good stand of grasses, including June, western needlegrass, western wheat grass, bluebunch wheat grass, and blue grama. Sandreed grass was found on the sandy spots. Mountain sage was the principal forb.

Field 19a.—This was originally broken in 1916 and abandoned in 1920. There was an excellent covering of grasses closely approaching native prairie conditions. The covering was composed of western needlegrass, green needlegrass, western wheat grass, bluebunch wheat grass, June grass, and blue grama. The principal forbs were mountain sage, snakeweed, goldenrod, and cinquefoil. Three other fields abandoned 19 years were studied. The grass covering had about the same density in these as in 19a with the species being about the same.

Field 20a.—This field was broken in 1915 and farmed to small grains until 1919, when it was abandoned. There was an excellent stand of grass which gave the appearance of a recovery nearly equal to native conditions. Western wheat grass, June grass, blue grama, western needlegrass, and bluebunch wheat grass were found in about the same proportion as in native prairie. The forbs consisted principally of mountain sage, snakeweed, and gumweed.

Field 20b.—This area supported practically the same vegetation as 20a with the addition of some sedge (Niggerwool) *Carex filifolia* L. Nutt.

Field 21a.—This was broken in 1915 and farmed to grain crops until 1918 when it was abandoned. The grasses were the most prevalent type of vegetation comprising the same species mentioned in field 20a. Cinquefoil and snakeweed were in about the same proportion as in the native prairie.

Field 22a.—This field was originally broken in 1914 and abandoned in 1917. It had an excellent covering of the climax grasses as mentioned in field 20a. Except for occasional spots of mountain sage this field was comparable to native prairie.

GENERAL DISCUSSION

From the foregoing discussions of abandoned fields, variations in the amount of re-vegetation can be noted. Since most of the fields

had been subjected to wind erosion, succession was more or less erratic and was correspondingly delayed. For the purpose of clarity it might be well to classify the succession arbitrarily into stages.

The primary or annual weed stage is found on fields abandoned from one to three or more years, depending on factors which will be discussed below. Any plants of the later stages of succession would grow here, but those best adapted to seed the new area rapidly enter first. It is natural, therefore, that the first stage should be a weed stage. The plants are scattered, and in dry years are small. The principal species which constitute this stage are the following weeds: *Grindelia squarrosa*, *Helianthus*, spp., *Lygodesmia juncea*, *Salsola pestifer*, *Sisymbrium altissimum*, and *Setaria viridis*.

The second, or mixed annual-perennial stage, may be found to occur on fields abandoned from two to four or more years. Here the species which enter in the first stage reach their greatest development and begin to disappear. During the latter part of this stage such grasses as *Agropyron smithii*, *Stipa comata*, *S. viridula*, *Sitanion hystrix*, and *Aristida purpurea* begin to assume importance. Perennial forbs, such as *Gutierrezia sarothrae*, *Liatris* sp., *Potentilla* sp., *Rosa* sp., *Sphaeralcea coccinea*, and *Artemisia frigida*, are prominent. As the stage advances the grasses assume more importance.

The third or perennial stage occurs in the fields abandoned from three to eight or more years. Here the various grasses are beginning to exert dominance and to form definite alternes. *Bouteloua gracilis*, *Koeleria cristata*, *Muhlenbergia cuspidata*, and *Agropyron spicatum* make their entry into the succession. The first three mentioned made their first appearance at about the seventh year of abandonment, increasing in importance as the period of abandonment increases. *Agropyron spicatum* was first found on fields abandoned for 12 years, giving one the impression that it enters the succession later than most of the other climax species. This late appearance may be ascribed to its being the dominant in the Palouse prairie which is marked by a generally higher rainfall. *Bouteloua gracilis* is relatively unimportant, except where grazing has been long continued or severe, and is best considered as marking the change toward the disclimax (8). Protected or lightly grazed areas contained only occasional clumps of grama, while the pastures heavily grazed were dominated by it. The tendency of grama to become more abundant the longer the abandonment and consequent grazing is shown from the data of fields 19a and 20a since there are four or five mid-grasses to the one short-grass. During this stage *Calamovilfa longifolia* forms a consociation on sandy soil.

A fourth stage is dominated by the perennial climax grasses to form the *Stipa-Agropyron* climax or faciation which no doubt occurs on fields abandoned from 8 to 12 or more years. This is especially true in terms of composition and to some extent of density. The climax species comprising this stage are *Stipa comata*, *S. viridula*, *Agropyron smithii*, *A. spicatum*, and *Koeleria cristata*.

Although these stages can be distinguished, there is an overlapping in the years of abandonment for each stage considered. The length of time required for the more desirable grasses fully to reclaim

abandoned fields varies on the average from 8 to 12 or more years. This time is dependent on many factors. Length of cultivation plays an important part in the rapidity of re-grassing. Fields cultivated for a year or two and then abandoned revert to the original cover much more rapidly than those tilled more intensively, or for a longer period of time. This indicates that rhizomes and crowns persist over several years of cultivation as was found in Kimball County, Nebraska.[5] The rate is not quite so rapid in Teton County, owing, in part at least, to lower rainfall.

Abandoned areas enclosed with or adjacent to virgin prairie pastures recovered more rapidly than those not so situated for the prairie areas constitute a source of seed, carried in by wind, water, or cattle. In cases of this kind moderate grazing seems to assist or hasten recovery, while close grazing has the opposite effect.

Erosion greatly hinders natural succession and under severe conditions may delay the final recovery many years or entirely prevent it from taking place. Size of abandoned field, whether cropped to non-intertilled or intertilled crops, also affects the rate of recovery. A long narrow abandoned strip recovers more rapidly than the same acreage in more the form of a square, providing there are seed grasses along one entire side.

One of the outstanding features regarding the vegetation of this section of the Great Plains was the fewer species of plants as compared to the larger number found in the central or southern parts. This seemed to be true in the early as well as the later stages of succession.

It seems that the maximum time necessary for complete recovery is shorter in this area than in some of the other sections studied. In Kimball County, Nebraska, this time was estimated to be from 10 to 30 or more years, while it is generally conceded that from 20 to 40 years are required in the Central and Southern Great Plains regions.

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PLACEMENT OF DOLOMITE, SUPERPHOSPHATE, AND BASIC SLAG FOR SOYBEANS, AUSTRIAN WINTER PEAS, AND VETCH[1]

W. B. ANDREWS[2]

THE importance of calcium and phosphorus for nitrogen fixation and the growth of legumes is generally recognized. The comparative value of small amounts of limestone in the drill and large amounts broadcast has been investigated (1, 2, 3, 4, 5, 6, 7).[3] Small amounts of limestone in the drill with the seed often produce excellent increases in the yield and in the nitrogen fixed by legumes. However, Klingebiel and Brown (5) found that fixation of nitrogen was considerably better where the larger quantities were broadcast. They also found that applying lime in the row with the seed produced larger yields of alfalfa containing a higher nitrogen content than applying the same quantity of lime on each side of the seed at a distance of half an inch from the seed.

The purpose of this paper is to report data on the placement of small amounts of dolomite, superphosphate, basic slag, and muriate of potash in the drill relative to soybean, Austrian winter pea, and vetch seed.

EXPERIMENTAL

The test on placement of dolomite, superphoshate, and muriate of potash for soybeans was conducted on Lufkin clay soil of pH 4.65, and for Austrian winter peas on Myatt fine sandy loam of pH 4.5. The placement of basic slag test for vetch was conducted on Myatt fine sandy loam of pH 4.5. The plots were 1/400 acre in size. Each plot was a single row 3.5 feet in width. The seed were sown by hand in a single drill. They were covered approximately 2 inches deep. The soybean seed were planted approximately 2 inches apart. The variety of soybeans was Biloxi. The vetch and Austrian winter peas were sown at the rate of 30 and 40 pounds per acre, respectively.

The dolomite and superphosphate were applied at the rate of 200 pounds of each, and basic slag at the rate of 400 pounds per acre. Muriate of potash was applied at the rate of 0, 50, 100, and 200 pounds per acre. The fertilizers were applied in turning plow furrows made at different depths and distances from the seed, as indicated in the respective tables. There were six replications of each treatment. The data are reported in Tables 1, 2, and 3. All seed were inoculated unless otherwise indicated.

RESULTS AND DISCUSSION

EFFECT OF PLACEMENT OF DOLOMITE, SUPERPHOSPHATE, AND MURIATE OF POTASH RELATIVE TO SOYBEAN SEED ON YIELD OF SOYBEANS

Where superphosphate was placed in contact with the seed and the

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[3]Figures in parenthesis refer to "Literature Cited", p. 341.

dolomite placed 4 inches to one side and 2 inches below the seed, the yield was 4,033 pounds per acre (Table 1). Even though the difference between the latter and the contact placement which produced 3,760 pounds per acre is not statistically significant, a difference of 564 pounds being required for significance, it indicates that the separation of the superphosphate and the dolomite probably had a beneficial effect. The beneficial effect in this case would be due to chemical reactions between the dolomite and superphosphate which would reduce the availability of the phosphorus. The beneficial effect of separating the dolomite and superphosphate is further borne out in the placement of the dolomite in contact and the superphosphate 4 inches to one side and 2 inches below the seed which produced 4,447 pounds per acre. The latter yield is significantly greater than that obtained with the contact placement of both dolomite and superphosphate and most of the other placements. Separating the dolomite and superphosphate in the latter case probably had two beneficial effects, *viz.*, (a) increasing the availability of the phosphorus and (b) making the environment more suitable for the soybean nodule bacteria where the dolomite was placed in contact with inoculated seed. Placing the dolomite and superphosphate 2 inches below the seed and 2 inches and 3 inches on one side produced 4,271 and 4,203 pounds per acre, respectively.

TABLE 1.—*The effect of placement of dolomite and superphosphate relative to the seed on the yield and nitrogen content of soybean hay.*

Plot No.	Placement of 200 lbs. dolomite and 200 lbs. superphosphate per acre relative to seed	Yield of air-dry hay, lbs. per acre	Percentage of nitrogen
1	1 in. below	3,777	1.50±0.085*
2	3 in. below	3,684	1.74±0.094
3	2 in. below 2 in. side	4,271	1.85±0.101
4	2 in. below 3 in. side	4,203	1.73±0.108
5	2 in. below 4 in. side	3,997	1.64±0.105
x	Check; not inoculated	3,111	1.51±0.156
6	1 in. below 2 in. side	3,816	1.75±0.092
7	3 in. below 2 in. side	3,843	1.73±0.133
8	Mixed with soil 3 in. below	3,889	1.67±0.065
9	Contact	3,760	1.67±0.082
10	Contact plus 50 lbs. muriate	2,936	1.59±0.115
y	Check; inoculated	3,133	1.55±0.012
11	Contact plus 100 lbs. muriate	2,867	1.42±0.109
12	Contact plus 200 lbs. muriate	1,909	1.17±0.049
13	Super contact, dolomite 4 in. side 2 in. below	4,033	1.47±0.079
14	Dolomite contact, super 4 in. side 2 in. below	4,447	1.83±0.100
15	Dolomite 4 in. side 2 in. below, super 4 in. side 2 in. below	3,817	1.83±0.012
	Standard error	196	
	Standard error of difference	277	
	Difference for significance	554	

*Standard error.

The harmful effect of placing muriate of potash in contact with the seed is brought out by the fact that the yield obtained where the

dolomite and superphosphate were applied in contact with the seed was 3,760 pounds per acre, and where 50, 100, and 200 pounds of muriate of potash were added to the dolomite and superphosphate in contact with the seed, the yields were reduced to 2,936, 2,867, and 1,909 pounds per acre, respectively. Muriate of potash reduced the stand and caused the soybeans to have a lighter green color.

EFFECT OF PLACEMENT OF DOLOMITE, MURIATE OF POTASH, AND SUPERPHOSPHATE RELATIVE TO SOYBEANS SEED ON NITROGEN CONTENT OF SOYBEANS

The nitrogen content of the soybeans receiving no fertilizer treatment was $1.55 \pm 0.012\%$. Placing the dolomite and superphosphate 2 inches below and 2 inches to one side of the seed increased the nitrogen content to $1.85 \pm 0.101\%$. The nitrogen content was $1.83 \pm 0.100\%$ where the dolomite was placed in contact and the superphosphate was placed 4 inches on one side of the seed and 2 inches below and $1.83 \pm 0.012\%$ where the dolomite and superphosphate were placed on opposite sides of the seed 4 inches away and 2 inches below. The addition of 200 pounds of muriate of potash to the contact placement of dolomite and superphosphate reduced the nitrogen content to $1.17 \pm 0.049\%$. The other increases in nitrogen content are not statistically significant. The fertilizer placements which produced high increases in yield also produced significant increases in nitrogen content.

EFFECT OF PLACEMENT OF DOLOMITE, SUPERPHOSPHATE, AND MURIATE OF POTASH RELATIVE TO AUSTRIAN WINTER PEA SEED ON YIELD

The yield obtained with dolomite and superphosphate together 2 inches below and 2 inches to the side of the seed was 1,767 pounds of dry peas (Table 2), superphosphate in contact and dolomite 2 inches below and 2 inches to the side produced 1,052 pounds, superphosphate on one side and dolomite on the other 2,084 pounds, and dolomite in contact and superphosphate to the side 2,189. The difference required for significance was 415 pounds per acre. When superphosphate was placed in contact with the seed, dolomite was no more effective in the contact than in the side placement. As was the case with soybeans, there is apparently a real increase in yield due to the separation of dolomite and superphosphate. The beneficial effect is apparently both chemical and biological.

With the mixture of superphosphate and dolomite placed 2 inches below the seed, the yield was 1,767, 1,943, and 1,398 pounds of air-dry peas per acre at 2, 3, and 4 inches to the side of the seed, respectively. When the mixture of dolomite and superphosphate was placed 2 inches to the side of the seed, the depth of placement of 1, 2, and 3 inches had no significant effect on the yield. Muriate of potash in contact with the seed reduced the yield very significantly when as little as 50 pounds of muriate of potash was applied.

Placing dolomite in contact with the seed probably and a beneficial effect on the inoculation. Inoculation alone increased the yield with-

TABLE 2.—*The effect of fertilizer placement on the yield of Austrian winter peas.*

Plot No.	Placement of 200 lbs. superphosphate and 200 lbs. dolomite per acre relative to seed	Yield of air-dry Austrian winter peas, lbs. per acre
1	1 in. below	1,440
2	3 in. below	1,244
3	2 in. below 2 in. side	1,767
4	2 in. below 3 in. side	1,943
5	2 in. below 4 in. side	1,398
x	No fertilizer	674
6	1 in. below 2 in. side	1,807
7	3 in. below 2 in. side	1,802
8	Mixed with soil to a depth of 3 in. below	1,471
9	Contact	1,089
10	Contact plus 50 lbs. muriate	745
11	Contact plus 100 lbs. muriate	644
12	Contact plus 200 lbs. muriate	475
x	No fertilizer or inoculation	76
13	Super contact, dolomite 2 in. below, 2 in. side	1,052
14	Dolomite contact, super 2 in. side, 2 in. below	2,189
15	Super one side, dolomite other side, 2 in. side, 2 in. below	2,084
	Standard error	147
	Standard error of difference	207
	Difference for significance	415

out fertilizer from 76 to 674 pounds of air-dry peas per acre. There was no indication that placement of the fertilizers affected the nitrogent content of Austrian winter peas.

EFFECT OF PLACEMENT OF BASIC SLAG RELATIVE TO THE SEED ON YIELD OF VETCH

The yield of air-dry vetch (Table 3) without fertilizer treatment was 1,100 pounds per acre. Placing the basic slag in contact with,

TABLE 3.—*The effect of placement of basic slag relative to the seed on the yield of vetch.*

Plot No.	Placement of 200 lbs. of basic slag per acre	Yield of air-dry vetch, lbs. per acre
1	No basic slag	1,100
2	Contact with seed	2,264
3	1 in. below seed	2,108
4	3 in. below seed	2,153
5	1 in. to side of seed, 1 in. below	1,848
6	2 in. to side of seed, 1 in. below	1,940
7	3 in. to side of seed, 1 in. below	1,617
8	4 in. to side of seed, 1 in. below	1,645
	Standard error	172
	Standard error of difference	243
	Difference for significance	486

1 inch below, and 3 inches below the seed increased the yield to 2,264, 2,108, and 2,153 pounds of air-dry vetch per acre, respectively. These treatments were all good and there was apparently no difference

between them. The yields were 2,108, 1,848, 1,940, 1,617, and 1,645 pounds of air-dry vetch per acre where the basic slag was placed 1 inch below and 0, 1, 2, 3, and 4 inches to the side, respectively. The side placements were all inferior to the contact or below placements.

SUMMARY AND CONCLUSIONS

A fertilizer placement test was conducted with soybeans and Austrian winter peas. The fertilizers used were dolomite, superphosphate, and muriate of potash. A basic slag placement test with vetch was also conducted. The data may be summarized as follows:

1. Placing the mixture of dolomite and superphosphate 2 inches to one side and 2 to 3 inches below the seed was superior to contact placement.
2. Muriate of potash in contact with the seed decreased the yield.
3. The best placement was dolomite in contact and superphosphate below and to the side of the seed. The data indicate that the separation of dolomite and superphosphate prevented undesirable chemical reactions and stimulated the nodule bacteria.
4. In general, the fertilizer placement producing the highest yield of soybeans produced the highest nitrogen content, but placement had no effect on the nitrogen content of Austrian winter peas.
5. Placing basic slag in contact with or below vetch seed was superior to side placements.

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INHERITANCE AND LINKAGE RELATIONSHIPS OF A CHLOROPHYLL MUTATION IN RICE[1]

N. E. JODON[2]

A VIRESCENT white-stripe chlorophyll deficiency in rice plants was found in 1933 in a heterozygous condition in an F_4 selection from a Kameji × Blue Rose cross. The emerging seedlings were nearly white with indefinitely bordered linear areas of chlorophyll. New leaves and emerging panicles also were deficient in chlorophyll. Counts made on segregating progeny in subsequent generations indicated that the inheritance of the virescent character was determined by a single recessive factor. It was noted also that the rate of development of chlorophyll varied from season to season, and that virescent plants tended to be smaller than normal plants.

The present paper reports the mode of inheritance and linkage relations of five character pairs in rice, *viz.*, normal vs. virescent, clustered vs. normal floret arrangement, common vs. glutinous kernels, purple vs. colorless apiculus, and late vs. early maturity, in a cross between C. I.[3] 4630 with strain No. 2912A21 breeding true for virescent seedlings and late maturity.

LITERATURE REVIEW

The literature on rice genetics originates from widely scattered sources and in some instances it is not possible to be certain of the identity of the characters reported by different workers. Jones (4)[4] summarized published data on F_2 ratios. Single-factor ratios were reported for green × white stripe and common × glutinous endosperm. Earliness and lateness were each reported as single factor dominants. Purple color in the apiculus was controlled by two or more factors. Ramiah, *et al.* (9) reported clustering as a single-factor dominant. The F_1 was intermediate, and a 1:2:1 ratio was obtained in the F_2. Ramiah and Ramanujam (10) found and illustrated a green-and-white-stripe single-factor recessive mutant, which probably was identical with the one reported here. Ramiah (8) obtained a trimodal curve for maturity in one cross from which the earlier and later strains bred true. In other crosses multiple factors were involved and reversal of dominance occurred in certain segregating selections. Jones, *et al.* (5) found 3 late : 1 early, 9 late : 7 early, and multiple-factor ratios.

Linkage between apiculus color and endosperm type was first reported by Yamaguchi, according to Matsuura (7). Yamaguchi also found a maturity factor in this linkage group, the order being apiculus—endosperm—maturity. Chao (1) assigned a factor for tawny glume color and one for leaf sheath color to this linakage group.

[1]Contribution from the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, in cooperation with the Louisiana Agricultural Experiment Station. Work conducted at Rice Experiment Station, Crowley, La. Paper also presented at the annual meeting of the American Society of Agronomy at New Orleans, La., November 24, 1939. Received for publication February 20, 1940.

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[3]C. I. refers to accession numbers of the Division of Cereal Crops and Diseases.

[4]Numbers in parenthesis refer to "Literature Cited", p. 346.

MATERIALS AND METHODS

In 1936 a cross was made between strain No. 2912A21 and C. I. 4630 after emasculation by the hot-water method (3). C. I. 4630 has a clustered arrangement of the florets on the panicle branches, deep purple apiculus, glutinous endosperm corresponding to waxy in maize, matures early, and produces normal green seedlings. Strain No. 2912A21 bred true for virescent seedlings, normal arrangement of florets on the panicle branches, common starch development, colorless apiculus, and late maturity. The F_1 seeds were germinated indoors and the seedlings were transplanted to the field after reaching a height of 4 or 5 inches. F_1 endosperms were common or non-glutinous. F_1 plants grown in 1937 were late in maturity, had normal chlorophyll, clustered florets, and purple apiculi. The F_2 data were obtained in 1938. Emergence of the F_2 plants was rather irregular due to unfavorable moisture conditions and cool weather, but the stand was satisfactory.

Virescent seedlings were staked as noted, but it was found that this character was classified more satisfactorily by the whiteness of the emerging panicle. Virescent and date of panicle emergence were recorded at 2- to 5-day intervals on tags which were attached to the panicles with paper clips. A single mature panicle was harvested from each of the 890 F_2 plants and classification of the three remaining characters was made in the laboratory. All plants having any tendency for the florets to be clustered were included in the "cluster" class without attempting to separate the fully clustered from the intermediates. Since rice is normally self fertilized, those segregating for endosperm character were classed as common. The purple apiculus was distinct and easily separated from the nonpurple.

EXPERIMENTAL RESULTS

Data in Table 1 show that the F_2 segregation for each of the five character pairs studied was in satisfactory agreement with a 3 : 1 ratio. A 3 : 1 ratio had been previously reported for red but not for purple vs. colorless apiculus. A few of the virescent segregates appeared to contain less chlorophyll than the parent strain, the panicles remaining white when nearly mature.

The assumption of a single basic or major factor for maturity with lateness dominant seems justified by the apparently bimodal form of the distribution of panicle emergence dates in F_2 as shown in Fig. 1.

The curve, based on 7-day periods, is somewhat irregular for the early group, but rapidly rises to a peak and declines rather abruptly for the late group. The effect of weather conditions must be considered in connection with irregularities in heading in rice. Heading is retarded by cool, cloudy, and rainy weather, whereas it is hastened by warm, clear, calm weather.

There was marked transgressive segregation for maturity as indicated by panicle emergence ranging from 22 days earlier than the early parent (C. I. 4630) to 39 days later than the late parent, a total range of 96 days. All plants heading before the late parent, i.e., up to August 22, were grouped as early. This covered approximately half the total heading period. At Crowley, La., August 20 is the heading date usually considered as separating early and midseason from late strains. Although the curve (Fig. 1) rises toward the peak for late maturity for the week ending August 22, it is not so high then as at

TABLE 1.—*Segregation for five characters in an F_2 of the cross virescent × C. I. No. 4630, cross No. 4-107a4.*

Character	Number of plants	Chi square, (3:1 ratio)	Probability
Chlorophyll:			
Normal	691		
Virescent	199	3.309	0.10–0.05
Total	890		
Floret arrangement:			
Cluster	673	0.181	0.70–0.50
Normal	217		
Total	890		
Type of starch:			
Common	673	0.181	0.70–0.50
Glutinous	217		
Total	890		
Apiculus color:			
Purple	665		
Colorless	225	0.037	0.90–0.80
Total	890		
Maturity:			
Late	678		
Early (Aug. 20 or earlier)	212	0.661	0.50–0.30
Total	890		

the peaks for early maturity. When all plants heading after August 12 were considered as late maturing, a deficiency in the early class was obtained. For the purpose of studying linkage relationships, however, lateness is considered here as a single factor dominant.

The Chi-square test for independence was used to detect association among the characters studied. All characters were found to be associated except floret arrangement and endosperm type. The recombination percentages calculated by the product method and with the aid of Immer's tables (2) are given in Table 2.

Fig. 2 shows the same data in the form of a chromosome map. The symbols used in Table 2 and Fig. 2 are those proposed by Kadam and Ramiah (6). The four qualitative factors are arranged as follows: *gu-as-v-cl*. The smallest linkage value obtained (7.5%) was that between *v* and *fl*, but the relative position of these two genes could not be determined because of conflicting data. Since the recombination percentage is 24.5 between *as* and *v*, 30.0 between *as* and *fl*, and 7.5 between *v* and *fl*, the indicated order is *as-v-fl*. Since the recombination percentage is 42.5 between *cl-as*, 34.5 between *cl-v*, and 40.5 between *cl-fl*, the indicated order is *as-fl-v-cl*.

It should be noted that Yamaguchi (7) reported that the arrangement of the factors he placed in this linkage group was *fl-gu-as*. Either different factors are involved from those in Yamaguchi's

TABLE 2.—*Percentage of recombinations among five characters in the cross virescent × C. I. 4630, cross No. 4-107a4.*

Characters	Chlorophyll	Floret arrangement	Endosperm type	Apiculus color	Maturity
Chlorophyll (v)	—	34.5	40.5	24.5	7.5
Floret arrangement (cl)	—	—	—*	42.5	40.5
Endosperm type (gu)	—	—	—	22.5	41.0
Apiculus color (as)	—	—	—	—	30.0
Maturity (fl)	—	—	—	—	—

*Independent. Chi square = 2.067. P = 0.20–0.10.

material or lateness in the cross reported here cannot be ascribed to a major single dominant factor. It is possible that the three recombi-

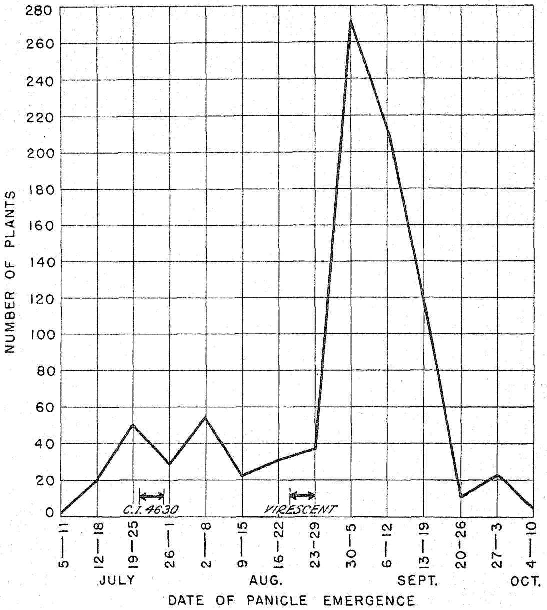

FIG. 1.—Distribution of dates of panicle emergence in F_2 of cross No. 4-107a4.

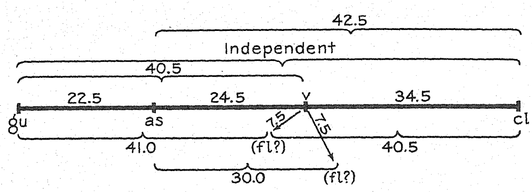

FIG. 2.—Linkage map, showing relative position of factors studied in cross No. 4–107a4 and their recombination percentages.

nation percentages, 40.5, 41.0, and 30.0, are approximations of 50% and that the *fl* 7.5% represents some physiological relationship of virescent with maturity. In another cross, however, the writer obtained linkage values of 30 and 37% between *as* and *fl*. The linkage value of 22.5% between *gu* and *as* agrees closely with the 20 to 22% obtained by Yamaguchi and Takahashi as reported by Matsuura (7), and the 22.34% obtained by Chao (1).

SUMMARY

A recessive virescent mutation (*v*) appeared in an F_4 Kameji × Blue Rose progeny row. In the F_2 generation of a cross No. 2912A21 (virescent) × C. I. 4630 (normal), virescence was found to be linked with three other recessive factors in the following order: *Glutinous-colorless apiculus-virescent-noncluster*. A maturity factor was apparently closely linked with virescent, but the relative position was not determined.

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EFFECT OF THE METHOD OF COMBINING THE FOUR INBRED LINES OF A DOUBLE CROSS OF MAIZE UPON THE YIELD AND VARIABILITY OF THE RESULTING HYBRID[1]

ROBERT C. ECKHARDT AND A. A. BRYAN[2]

LARGE scale production of inbred lines from several varieties of corn was begun at the Iowa Agricultural Experiment Station in 1922. Hundreds of lines were started, the majority of which have been discarded, but a number of good ones have been produced from each of the varieties. The task remains of combining the best of them to produce the most desirable hybrid combinations. Even with relatively few lines, making and testing of all possible hybrid combinations is a staggering task. Thus with only 40 inbreds, 780 single crosses and 274,170 double crosses are possible.

This paper reports the effect upon the yield and variability of two methods of making double crosses among lines from different varieties.

REVIEW OF LITERATURE

Jenkins (3)[3] was the first to use the performance records of single and inbred-variety crosses in predicting the performance of double crosses. He used four different methods as follows (a) the mean values of all possible single crosses among the four lines, (b) the mean value of the four single crosses not used as parents, (c) the mean of all single-cross tests involving each one of the four parent lines, and (d) the mean of the inbred-variety crosses of the four lines. The methods involving single-cross combinations were found to be most reliable. The most important advantage of the inbred-variety cross method was that it permitted the inclusion of all the inbred lines in the tests each year.

Doxtator and Johnson (2) used Jenkins' method (b) in which the four single crosses not used as parents in the double cross were averaged to predict the character desired. They were able to predict the relative yields of double crosses very closely.

Anderson (1) also concluded that double cross yields could be predicted closely by averaging the yield of the four single crosses not used as parents of the double cross.

Wu (6) compared single cross yields in which the inbred parents were derived (a) from the same single cross, (b) from single crosses having one line in common, and (c) from unrelated single crosses. Crosses of closely related material (a) were significantly lower in yield than those from (b) and (c). Crosses of the inbreds from (b) were not significantly different in yield than crosses among inbreds from (c), the unrelated inbreds.

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[1]Contribution from the Farm Crops Subsection, Iowa Agricultural Experiment Station, Ames, Iowa, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, cooperating. Journal paper J667. Project 163. Received for publication February 21, 1940.

[2]Agent and former Agronomist, respectively, Division of Cereal Crops and Diseases; Collaborators, Agronomy Section, Farm Crops Subsection, Iowa Agricultural Experiment Station.

[3]Figures in parenthesis refer to "Literature Cited", p. 353.

MATERIAL AND METHODS

Four inbred lines from each of three varieties were used. They were as follows: I 159, I 205, I 224, and I 233 from Iodent; L 289, L 317, L 324, and L 326 from Lancaster Surecrop; and Bl 339, Bl 345, Bl 349, and Bl 351 from Black Yellow Dent. Black Yellow Dent and Iodent are selections from Reid Yellow Dent, but Lancaster Surecrop is a Pennsylvania variety, distantly if at all related to the other two varieties.

Two methods were used in making the double crosses. Designating inbreds from one variety as A and B and inbreds from a second variety as Y and Z, double crosses were made as follows: $(A\times B)\times(Y\times Z)$ and $(A\times Y)\times(B\times Z)$. Paired double crosses produced in this manner were compared to determine the better method of combining the inbreds. Only one of the double crosses $(A\times Y)\times(B\times Z)$ or $(A\times Z)\times(B\times Y)$ was used, the particular combination chosen depending on available seed.

Double crosses composed of four inbred lines from the same variety were included to compare with those hybrids composed of inbreds from two varieties. Two open-pollinated varieties and two commercial hybrids were included as standards of comparison.

The field plots in 1936 and 1937 were arranged in randomized blocks. In 1938 the pair $(A\times B)\times(Y\times Z)$ and $(A\times Y)\times(B\times Z)$ was treated as a unit in the randomization process and then the hybrids within the pair were randomized. The plots were two by ten hills and each entry was replicated six times. Acre yields each year were computed on the basis of shelled grain containing 15% moisture.

Data were taken in 1936 on ear height and in 1937 on ear height, plant height, ear weight, ear length, and ear diameter in the following manner: In each hill of the plots (2×10 hills) in the replications sampled, one stalk was chosen at random and tagged. In the fall, plant and ear heights on these 20 plants per plot were determined and the ears dried and weighed individually. Ear length and ear diameter were recorded at the time of weighing. Ear diameters were taken about one-sixth of the distance from the butt to the tip. In 1936 three replications (60 plants) and in 1937 five replications (100 plants) were sampled for the studies. From these data the variance within strains was computed for each character.

EXPERIMENTAL RESULTS

In 1936, double crosses of the formula $(A\times B)\times(Y\times Z)$ outyielded their comparable $(A\times Y)\times(B\times Z)$ double crosses by an average of 3.08 bushels. In only 2 of the 12 pairs did double crosses of the formula $(A\times Y)\times(B\times Z)$ yield more than the double crosses of formula $(A\times B)\times(Y\times Z)$. In these cases the inbred lines were from Black Yellow Dent and Iodent, both selections of Reid Yellow Dent. A significant difference in favor of the $(A\times B)\times(Y\times Z)$ double crosses was shown by an X^2 test.

In 1937, the mean yields for the $(A\times B)\times(Y\times Z)$ double crosses exceeded the yield of their comparable $(A\times Y)\times(B\times Z)$ double crosses by 3.72 bushels, but the absolute yields were much higher in 1937 than in 1936. When three pairs were omitted from the calculations because of poor stands for at least one of the pair, the mean difference between the combinations produced by the two methods was not significant. Notwithstanding this general relationship, the

highest yielding hybrid, Iowa Hybrid 3110 (I 159×I 224)×(L 289×L 317) was 18.2 bushels above its comparable hybrid, Iowa Hybrid 3490 (I 159×L 289)×(I 224×L 317).

In 1938, another excellent year for maize, the yield differences between hybrids combined (A×B)×(Y×Z) vs. (A×Y)×(B×Z) were highly significant and in favor of the first arrangement. As these were paired in the field plot arrangement in the 1938 test, the 1938 data afford the more accurate test of hybrid comparisons between members of a pair.

Table 1 gives the yields of the hybrids for the 3-year period 1936, 1937, and 1938. The analysis of variance, shown in Table 2, reveals that the variance between the methods of combining the lines was highly significant. Years account for most of the total variation and this variance likewise is highly significant. Differences between pairs were highly significant as was the interaction pairs×years. Drouth conditions in 1936 and favorable conditions in 1937 and 1938 resulted in yields of maize which differed greatly. This accounts for the great variation between years. The variance ascribed to the interaction of pairs×years is highly significant because of the failure of the pairs to keep the same relative rank throughout the 3-year period. The significance of pairs by years interaction confirms other yield test results in which Iowa Hybrid 13 has done relatively better in drouth seasons while Iowa Hybrid 3110 has done relatively better in favorable maize seasons.

The F values for ear height in 1936 and those on ear height, plant height, ear weight, ear length, and ear diameter in 1937 are shown in Table 3. They were computed by dividing the "within" sum of squares for double crosses of the formula (A×Y)×(B×Z) by the similar sum of squares for the (A×B)×(Y×Z) double crosses.

In 1936, the variance for ear heights for the (A×B)×(Y×Z) group was not significantly lower than the variance for the (A×Y)×(B×Z) group, but in 1937 the lower variance of the (A×B)×(Y×Z) group was highly significant. No significant difference was found between the two groups in plant height, ear weight, or ear diameter, but a highly significant difference was found in ear length, with the (A×B)×(Y×Z) double crosses having the lower variance.

DISCUSSION

A variety of maize is composed of many different genotypes. Taken together, the plants of any variety have a certain gene frequency for their characters. The sum total of the gene frequencies for all characters distinguish and characterize the variety. Black Yellow Dent, Osterland Yellow Dent, and Iodent were selected from Reid Yellow Dent and through the selection process, the gene frequencies affecting the development of many characters were changed. Other gene frequencies were little affected by the selection process. Varieties such as Lancaster Surecrop have gene frequencies differing markedly from the varieties selected from Reid Yellow Dent.

Jenkins (4, 5) has shown that inbred lines achieve stability, so far as the average yield of their hybrid progeny is concerned, rather early

TABLE 1.—*Acre yields of double crosses for the three-year period, 1936, 1937, and 1938.*

Strain or cross No.	Pedigree	Acre yield in bushels in the year indicated			
		1936	1937	1938	Av.
	Black Yellow Dent	20.7	75.5	90.1	62.1
	Krug	25.3	60.5	88.6	58.1
Iowa Hybrid 939	(I205 ×L289) ×(Os420 ×Os426)	31.2	94.6	101.9	75.9
Iowa Hybrid 13	(L317 ×Bl349) ×(Bl345 ×Mc401)	44.9	87.1	117.8	83.3
3474	(I 159 ×I 224) ×(I 205 ×I 233)	31.9	73.9	101.3	69.0
3482	(I 159 ×I 233) ×(I 205 ×I 224)	25.7	65.1	104.1	65.0
3628	(L 289 ×L 317) ×(L 324 ×L 326)	28.1	90.1	93.8	70.7
3641	(L 289 ×L 324) ×(L 317 ×L 326)	33.6	93.5	102.1	76.4
3669	(Bl 339 ×Bl 345) ×(Bl 349 ×Bl 351)	32.4	81.1	97.7	70.4
3670	(Bl 339 ×Bl 349) ×(Bl 345 ×Bl 351)	29.5	85.1	101.1	71.9
3110	(I 159 ×I 224) ×(L 289 ×L 317)	36.9	111.1	117.3	88.4)
3490	(I 159 ×L 289) ×(I 224 ×L 317)	29.1	92.9	106.5	76.2)‡
3477*	(I 159 ×I 224) ×(L 324 ×L 326)	32.9	85.4	107.3	75.2)
3492*	(I 159 ×L 324) ×(I 224 ×L 326)	29.7	86.8	99.8	72.1)‡
3535	(I 205 ×I 233) ×(L 289 ×L 317)	30.9	88.2	109.1	76.1)
3558	(I 205 ×L 289) ×(I 233 ×L 317)	27.4	90.7	105.6	74.6)‡
3537*	(I 205 ×I 233) ×(L 324 ×L 326)	38.7	94.6	106.8	80.0)
3561*	(I 205 ×L 324) ×(I 233 ×L 326)	35.4	64.8	102.5	67.6)‡
3478	(I 159 ×I 224) ×(Bl 339 ×Bl 345)	30.2	85.7	106.0	74.0)
3493	(I 159 ×Bl 339) ×(I 224 ×Bl 345)	30.9	90.6	108.7	76.7)
3111*	(I 159 ×I 224) ×(Bl 349 ×Bl 351)	34.3	91.0	49.9	62.6)†
3495*	(I 159 ×Bl 349) ×(I 224 ×Bl 351)	32.7	86.7	109.9	59.7)†‡
3538	(I 205 ×I 233) ×(Bl 339 ×Bl 345)	30.5	86.2	113.7	76.8)
3562	(I 205 ×Bl 339) ×(I 233 ×Bl 345)	34.5	77.1	105.9	72.5)‡
3540*	(I 205 ×I 233) ×(Bl 349 ×Bl 351)	36.7	91.2	105.7	77.9)
3565*	(I 205 ×Bl 349) ×(I 233 ×Bl 351)	33.9	78.4	100.5	70.9)‡
3629	(L 289 ×L 317) ×(Bl 339 ×Bl 345)	33.3	87.0	104.7	75.0)
3716	(L 289 ×Bl 339) ×(L 317 ×Bl 345)	27.1	89.0	100.4	72.2)‡
3114	(L 289 ×L 317) ×(Bl 349 ×Bl 351)	40.5	98.7	114.0	84.4)
3643	(L 289 ×Bl 349) ×(L 317 ×Bl 351)	36.5	97.0	103.7	79.1)‡
3666	(L 324 ×L 326) ×(Bl 339 ×Bl 345)	35.4	94.9	94.6	75.0)
3717	(L 324 ×Bl 339) ×(L 326 ×Bl 345)	27.7	84.0	93.5	68.4)‡
3667	(L 324 ×L 326) ×(Bl 349 ×Bl 351)	43.3	93.9	101.6	79.6)
3668	(L 324 ×Bl 349) ×(L 326 ×Bl 351)	41.7	95.2	96.0	77.6)‡
	Average......................	33.9	90.1	105.0	

*Not used in the analysis of variance because of poor stand.
†Two-year average.
‡Higher yield for (A ×B) ×(Y ×Z) double cross.

in the inbreeding process. Presumably this is because equal numbers of dominant genes will be preserved by chance through successive generations of inbreeding due to the probability that the modal classes will be represented by the sample selected. Similarly, it might be expected that many of the inbred lines from a single variety would have many favorable growth genes in common. If a variety has many genes favorable for a given trait, the probability is high that most of the inbred lines derived from this variety will receive favorable genes

for this trait. Inbred lines from another variety, especially one that is distantly related, would presumably differ genetically from those of the first variety to a greater extent than they would from each other.

TABLE 2.—*Analysis of variance of the data on acre yield presented in Table 1.*

Source of variation	D/F	Net sum of squares	Mean square	F value
Method of combining	1	192.00	192.00	16.30**
Pairs	7	619.02	88.43	7.51**
Years	2	46,207.87	23,103.93	1,961.28**
Methods × pairs	7	201.49	28.78	2.44
Methods × years	2	7.39	3.69	0.31
Pairs × years	14	779.08	55.65	4.72**
Methods × pairs × years	14	164.99	11.78	—
Total	47	48,171.84		

**Highly significant (1% level).

TABLE 3.—*F values for the characters studied.**

Year	Ear height	Plant height	Ear weight	Ear length	Ear diameter
1936	1.03	—	—	—	—
1937	1.25**	1.06	1.03	1.12†	1.07

*An F value greater than 1.00 indicates less variation in the (A×B)×(Y×Z) double cross.
†Significant (5% level).
**Highly significant (1% level).

Since, as Jenkins has stated (3), "In any double cross, the genes of each of the four parental lines are united only with the allelemorphs of the two lines which entered the double cross from the opposite parent," the highest yielding double cross involving any four inbred lines should be the one which utilizes the two lowest yielding single crosses among the four lines as its parents. The two inbred lines from the same variety would presumably be somewhat alike genetically and therefore would perform best when entering the double cross from the same side of the parentage. On the average, inbred lines from different varieties would presumably have more favorable growth genes which are not common to each other and should perform best when entering the double cross from opposite parents.

The double crosses of formula (A×B)×(Y×Z) out-yielded their comparable double crosses 11 times out of 12 in a 3-year average (Table 1). The difference was highly significant. In only one pair, Iowa Hybrid 3478 (I 159×I 224)×(Bl 339×Bl 345) vs. Iowa Hybrid 3493 (I 159×Bl 339)×(I 224×Bl 345), did the hybrid combining inbreds from two varieties into the single crosses yield more than by combining inbreds from the same varieties into the parent single crosses. This exception was consistent for the 3 years during which the experiment was conducted and is explicable because Iodent and Black Yellow Dent both were selections from Reid Yellow Dent and would have many genes in common.

Not only did the (A×B)×(Y×Z) double crosses usually outyield the (A×Y)×(B×Z) double crosses, but the highest yielding double

crosses were those which combined one single cross of Lancaster inbreds with a single cross of Black Yellow Dent or Iodent inbred lines. The greatest hybrid vigor came from crossing single crosses distantly related.

The desirability of combining inbred lines from the same variety into the single-cross parents of double crosses is confirmed by experiments of Doxtator and Johnson (2) and Anderson (1). Doxtator and Johnson concluded the combination (11×14)×(374×375) had been selected as the most desirable double cross at the Waseca station. Inbreds 11 and 14 are from the Minnesota 13 variety, while inbreds 374 and 375 are from Reid Yellow Dent. Anderson (1) used two inbred lines from Reid Yellow Dent and three inbred lines from Golden Glow. In every test in which the two inbreds from Reid Yellow Dent were combined with the inbreds from Golden Glow into all possible double cross combinations the highest yield occurred when the two inbred lines from Reid Yellow Dent were combined in one single-cross parent and two inbreds from Golden Glow combined in the other single-cross parent.

With the exception of Iowa Hybrid 3641 (L 289×L 324)×(L 317×L 326), every pair of hybrids containing inbreds from two varieties had at least one member which had a higher yield than those hybrids from inbreds out of the same variety. The lower yield of the hybrids from inbreds all from the same variety is probably due to close relationship.

The degree of relationship among the parental lines also can be attacked by measuring the relative variability of the two kinds of double crosses. If the double cross (A×B)×(Y×Z) is significantly less variable for a particular character than the double cross (A×Y)×(B×Z), it can be reasoned that the two parental single crosses (A×B) and (Y×Z) each involved inbreds carrying many genes in common for the trait measured, or at least carrying more genes in common than would be the case of A vs. Y and B vs. Z.

Ear height variance as determined in 1936 showed no significant difference between methods of combining inbred lines, but in 1937 the lower variance for the (A×B)×(Y×Z) crosses was highly significant. The crop season of 1937 was much more favorable for maize production than was the drouth year 1936.

The differences in variance for ear weight and ear diameter between (A×B)×(Y×Z) vs. (A×Y)×(B×Z) double crosses were not significant. Ear length, however, was significantly less variable in the (A×B)×(Y×Z) double cross (Table 3). The Lancaster inbreds as a rule are long and slender, while the Black Yellow Dent and the Iodent inbreds are shorter and thicker.

SUMMARY

In double crosses involving two inbreds from each of two varieties, the combinations which brought together the inbreds of the same variety in the parental single crosses were consistently higher yielding.

The highest yielding double crosses were those that combined single crosses of widely different parentage.

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Significantly lower variances for ear height and ear length resulted from combining two inbreds from the same variety in each single cross parent. Lower variances were also found for plant height and ear weight, although in the case of these two characters the differences associated with method of combining were not statistically significant.

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RELATION OF BORON TO HEART ROT IN THE SUGAR BEET[1]

T. R. Cox[2]

A DISEASED condition of sugar beets hitherto not reported for this country was observed by Kotila (22)[3] in Gratiot County, Michigan, in 1932. It was noted in several other counties in 1933 and in Gratiot, Saginaw, Tuscola, Bay, Isabella, Clinton, Huron, and Ingham counties of Michigan and in Henry County, Ohio, in 1934. Subsequent studies by Kotila and Coons (23) showed that the diseased condition was due to a deficiency of boron, and in accord with the reports of European workers the disease was called heart rot.

Recent surveys by other workers (8) have indicated that some of the beet soils of Michigan have a boron content inadequate for the needs of a normal crop unless weather conditions are very favorable. As this deficiency of boron became more generally known, requests were soon received from beet growers for advice on the use of boron, and from fertilizer manufacturers as to the wisdom of preparing special fertilizers containing a low percentage of borax or boric acid. Accordingly, the Soils Section of the Michigan Experiment Station started field experiments in 1936 and greenhouse experiments in the spring of 1937 to test the value of borax as a control for heart rot on Michigan soils and to obtain information relative to the accumulation of boron in soils after repeated applications. Some of the results of these preliminary experiments are reported in this paper.

HISTORICAL

Since most of the literature pertaining to boron deficiency in sugar beets has been published in foreign journals and for that reason is not easily accessible to many interested persons, a rather broad review of the subject is herein attempted.

Studies by Paasch (30) in Germany on the cause and control of heart and dry rot indicate with a high degree of certainty that the disease now recognized as due to boron deficiency was observed in certain sections of Germany as early as 1886. His study of the records of incidence of heart rot of beets in relation to meteorological conditions from 1886–1929, inclusive, shows a marked prevalence in periods of protracted drought between mid-June and mid-September. Esmarch (12) made a corresponding report from Germany in 1928. Gram (18), Meyer-Bahlburg (27), Hauley and Mann (19), Fron (13), and others studying the disease more recently as a boron deficiency are in accord with this early observation that drought is very conducive to the disorder.

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[1]Contribution from the Soils Section, Michigan State College, East Lansing, Mich. Authorized for publication by the Director as Journal Article No. 424 (n. s.) of the Michigan Agricultural Experiment Station. Taken from a thesis submitted to the Graduate School of Michigan State College in partial fulfillment of the requirements for the degree of master of science. Received for publication February 24, 1940.

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[3]Figures in parenthesis refer to "Literature Cited", p. 368.

The association of boron deficiency with alkaline conditions seems to follow the investigations of many early workers attempting to trace the disease to some definite cause. Arrhenius (1) reported greater infestations in 1924 with slightly acid or nearly neutral soil conditions in either field or pot experiments. Garbowski (15), in a report for Poland, Pomerania, and Silesia for the season of 1921–22, indicates by the following statement that heart rot was prevalent in his territory: "Cases were also observed of a rot of the youngest leaves in the heart of the crown, correlated with a dry rot of the roots, stated to be due to the accumulation of alkaline salts in the soil; later the diseased tissues may be invaded by parasitic fungi."

Gallegher (14) investigated by extensive survey in 1928 the relation of soil reaction to failures of the beet crop in sections of Ireland and found that areas in which the disease was prevalent occurred on highly alkaline soil. A soil reaction of pH 6.5 appeared to be optimum for the normal development of the sugar beets while a reaction above pH 8.0 was especially conducive to the disorder. It is further pointed out that the maximum pH tolerance is higher in the humid Irish climate than in a drier climate such as Switzerland's where pH 7.0 is the point above which the disease is most severe.

Verhoven (37) of Holland reported a form of heart rot supposedly associated with excess alkalinity and dry weather, and Van Poeteren (36) reported for 1925 that excessive alkalinity of the soil is primarily responsible for a diseased condition similarly described. In 1930, Paasch (30) recommended that, as an aid in controlling heart and dry rot of beets in Breslou, Germany, calcareous fertilizers be avoided for dry alkaline soils.

Rambousek (32) reported a heart rot in Czechoslovakia for 1923 in which *Phoma betae* and other species of organisms apparently played a part. In order to prove whether or not soil conditions were important causal factors, Rambousek attempted to reproduce the same disease by introducing a virile culture of *Phoma betae* into healthy beets. His efforts to produce the disease failed consistently and he naturally concluded that other factors than bacteria contribute to the disease.

There is a striking correlation of symptoms reported from investigations completed prior to discovery of the boron relationship and those carried on afterwards. Rambousek (31) pointed out that the cavities or "growth cracks" under the heart caused by rapid growth should not be confused with the diseased condition, heart rot. Verhoven (37) described his "galloping heart rot" associated with alkalinity and dry weather as affecting the youngest leaves which turn black and die, followed by crown decay. McLarty (26) described with identical symptoms a rot of seed bearing, long red mangel beets. A well-illustrated paper by Kruger and Wimmer (25) in 1927 describes the heart and dry rot disease. They conclude that faulty nutrition or metabolic disturbance is the cause of the disease and that it is not pathogenic as previous workers had believed. They did not, however, indicate any belief or knowledge that boron deficiency was the nutritional factor involved.

The best early description of the disease is given by Gaumann (16, 17) of Switzerland who states that a soil pH of 7.8 gives incidence of the disease too great to allow profitable production of sugar beets. The following points are listed from his observations reported in 1925 because they correspond so perfectly with symptoms induced by boron deficiency a few years later by Brandenburg:

1. Dark discoloration of inner concave side of petioles of medium sized leaves, accompanied by frequent deformation of leaves.

2. Characteristic zonate fissures in concave side of petiole. Heart rot in advanced cases.
3. Development of symptoms without any trace of *P. betae* infection.
4. Based on chronological observations of symptoms, involvement of two distinct pathological processes, (a) primary physiological disturbance and (b) secondary parasitic attack.

A publication by Brandenburg in 1931 (4) describes the first reported experiments in which typical heart rot symptoms were produced by depriving Eckendorfer fodder beets of the element boron. His lead to the study is credited to recent physiological investigations with other plants, including the work by Brenchley and Warington (7) which demonstrated that plants of *Vicia fabia* deprived of adequate boron became diseased in a manner similar to that of sugar beets affected with heart rot.

In his initial experiment, plants from sterilized seeds were grown in glass vessels containing v.d.Crone's solution (pH 6 to 7). By the addition of 0.5 to 0.7 mg per liter of boric acid to this nutrient solution, heart rot symptoms were eliminated. The results of later experiments in the greenhouse and field by Brandenburg (5, 6) corroborate and amplify his early findings. The symptoms described were very much the same as those described by Gaumann (16), and already outlined in this paper.

Field experiments reported in 1932 by Brandenburg (5) included applications ranging from 2 to 20 kg per hectare, and showed that an application of 3 kg per hectare of boric acid (about 2.7 pounds per acre) gave optimum results. An increase in yield of 34.8% over the control acreage resulted. Another report by the same author in 1935 (6) indicates complete control of heart rot in field experiments in Holland and Germany by application of 20 to 25 kg per hectare of boric acid. The beneficial effects were found to persist the second year. A survey reported in the same paper found the sandy soils throughout the southern province of Holland to be more or less deficient in boron. Analysis of the ash of healthy beets showed a content of 0.36 to 0.442% boric acid while the ash of diseased beets contained only 0.105 to 0.287%.

Studies by Kotila (22), Kotila and Coons (23) and Coons (10) were undertaken after their discovery of the disease in 1932. For almost a year the nature of the disease remained somewhat a mystery. Kotila suspected lightning injury when the specimens examined were found to be free from pathogenic organisms, but decided on further study that the conditions noted were not characteristic of lightning injury. When reports of European workers finally appeared in the literature and came to their attention, experiments were started at once which verified the suspected boron relationship. The symptoms described are the same, if not more inclusive, than those described by European workers.

Kotila (22) stated that Michigan soils seem to have enough boron to maintain normal growth until early August, and that affected plants are usually found on knolls or elevated portions of fields. A cursory survey (23) of some of the lighter soils with porous subsoils, found to be most deficient in boron, indicated occurrence of symptoms in severe form in as much as 15% of the stand of beets, and in incipient stage in at least 25% of the remaining stand.

Gram (18) found that heart and dry rot of sugar beets and mangels was prevented by application of 15 kg per hectare of borax. The more profitable application of 30 kg per hectare gave a toxic residual effect the second year. Jamildinen (21) reported from Finland that 5 kg of boric acid per hectare reduced the number

of diseased plants from 49.1% to 7.6% and increased yields from 11.4 to 20.8 metric tons per hectare.

Observations and experiments by Wimmer and Ludecke in Silesia (38) for the three year period, 1929–32, did not support the idea that boron deficiency is the cause of heart rot. Likewise, Solunskaya (35) attempted to discredit the general observation of other workers that alkalinity is conducive to a deficiency of boron by chemically "tying up" the soil supply of boron. The greater foliage produced under alkaline conditions, she explained, demands a greater supply of boron and hence the deficiency.

That parasitic fungi play only a secondary role in heart rot was aptly demonstrated by Hirsch (20) who inoculated at the same time normal, healthy beets and boron deficient beets with active cultures of three different species of rot fungi. There was no appreciable effect on the healthy beets whereas the latter showed a marked acceleration of heart rot. Observations by Bergenin and Foex (2) indicated that boron deficiency predisposes the plant to invasion by *Phoma betae.*

EXPERIMENTAL

Three different experiments conducted in the greenhouse and laboratory are reported in this paper, as follows: (a) Studies with sugar beet seedlings grown in sand cultures, (b) studies with field-grown sugar beets which showed marked boron deficiency symptoms, and (c) experiments designed to furnish information on the solubility of borax after application to the soil.

SEEDLINGS IN SAND CULTURES

The object of this experiment was to produce for observation and study the symptoms of boron deficiency at various stages of development. Seedlings germinated from commercial sugar beet seed were transplanted into glazed, 1-gallon, earthenware jars. Each jar contained 5 kg of a fine white silica sand, thoroughly washed with water but otherwise not purified. The moisture content of each jar was maintained at 10% by the daily addition of distilled water. Uniform seedlings were selected, and three were planted in each jar.

Only C. P. chemicals were used in the basal nutrient solution. In no cases did the analysis of the chemicals indicate the presence of boron. The basal nutrient treatment formulated and applied in essentially the manner outlined by Muckenhirn (28) contained a desirable application of all minor elements other than boron. Boron was applied in the form of $Na_2B_4O_7.10H_2O$ (borax) at rates of 0, 1.2, 2.4, 3.6, 5.9, and 11.9 mg per jar. Each treatment was replicated four times. After heart rot had appeared in severe form in the control plants, a moderate application of boron was made to determine whether or not a recovery would occur.

FIELD-GROWN BEETS IN SAND CULTURES

The beet roots used in this experiment were taken from fields the second week of October, just prior to harvest. They were chosen as specimens showing the characteristic symptoms described in the literature as boron deficiency. Presumably, the soil supply of available boron was inadequate to normal maturation in the latter part of the growing season, and it was on the basis of this assumption that an experiment was set up to prove or disprove that boron was the limiting factor.

Eleven roots showing definite and fairly uniform heart rot or deficiency symptoms were chosen. The entire foliage was removed close to the crown, as it

is with mother beets in preparation for seed production. The beets were then split in half and transplanted into 1-gallon, glazed, earthenware jars, filled with a convenient amount of white silica sand. One-half of each beet was transplanted to a jar receiving the basal nutrient solution, complete except for boron. The other half was placed in a jar which received in addition $Na_2B_4O_7.10H_2O$ (borax) at the rate of 2.4 mg per jar. Under regulated conditions of moisture, the growth of the half beets was observed in the greenhouse for a period of about 4 weeks, after which there seemed to be little further development. The relative development of corresponding halves was carefully noted in the course of the experiment and any abnormal habits of foliage resembling deficiency symptoms were followed closely. Additional stimulating amounts of boron were applied to the jars at the end of the first 4 weeks and at subsequent intervals thereafter.

BORAX SOLUBILITY IN NATURAL SOILS

As result of certain experiments not reported in this paper, some pot cultures were available which were of slightly acid Napanee loam and slightly alkaline Thomas sandy loam, and on which two crops of sugar beets had been grown after applications of borax at rates ranging from 2.5 to 80 pounds per acre. It was thought that soil tests for available boron made on these cultures after they had been standing for approximately one year might reveal information regarding the possibilities of boron accumulation in soils.

Further information on the chance for boron accumulation was obtained by analyzing leachates from these 1-year-old pot cultures. To obtain the leachates the pots were kept flooded with distilled water until a certain quantity of solution had passed through a small hole near the bottom of each pot. The leachate was collected in 2,500 ml. portions. The quantity of B_2O_3 in each portion was separately determined according to the method described below.

METHODS OF ANALYSIS

The soil analyses were made, except for minor variations, according to the method described by Cook and Millar (9). A smaller sample of soil was used, but the proportion of extracting solution to soil was the same. The extraction was made with 0.02N HCl instead of a weak solution of H_2SO_4.

The distillation procedure was essentially the same. The boron in the anhydrous extract was distilled as methyl borate from an acid solution of absolute methyl alcohol into water made alkaline with Na_2CO_3. In alkaline solution the volatile methyl borate is hydrolyzed to a non-volatile form and can thus be retained in solution for titration. Rosolic acid (aurin) was used as the indicator in the micro-titration.

Analyses for sucrose were made under supervision of the Experiment Station chemist. Horne's dry lead acetate method was used for precipitation of impurities, and the sucrose content of the samples was determined with a 400 ml.-tube polariscope. Impurities of each sample were determined with the dipping or immersion type refractometer before sucrose determinations were made.

RESULTS AND DISCUSSION

SEEDLINGS IN SAND CULTURES

That boron plays an essential role in the growth and development of sugar beets is definitely shown by the results presented in Table 1.

The average yield from replicated jars receiving 11.9 mg borax in two applications was 80% greater than the average yield from control jars. The maximum concentration of borax at any time in the period of growth of the seedlings in this experiment was around 12 mg per liter of nutrient solution.

TABLE 1.—*Influence of different concentrations of boron on the yield of sugar beet seedlings grown in quartz sand and cultures.**

Treatment†	Relative yields			Symptoms developed	
	Tops and roots	Tops	Roots	Tops	Roots
No boron	100	100	100	Marked deficiency	Same
1.2 mg $Na_2B_4O_7.10\,H_2O$ at outset	148.8	146.4	151.1	Deficiency	Same
4.8 mg $Na_2B_4O_7.10H_2O$ after severe deficiency became evident	118.8	114.8	122.8	Deficiency on first growth	Same
7.1 mg $Na_2B_4O_7.10H_2O$ in divided applications	150.7	150.4	151.0	None	None
11.9 mg $Na_2B_4O_7.10H_2O$ in divided applications	182.4	184.7	180.0	None	None
23.8 mg $Na_2B_4O_7.10H_2O$ in divided applications	177.4	191.3	163.5	Slight toxicity	None

*Yields of controls are represented by 100 and all results based on the average green weight of four replicates per treatment.
†All jars received equal applications of the basal nutrient solution.

On the basis of the growth and development noted in the greenhouse seedlings, it appears that the seedlings grown in jars which received 11.9 mg borax per jar had the nearest to an optimum application. When the application was increased to 23.8 mg borax per jar there was no indication of toxicity except for a slight but hardly significant depression in the yields of tops and roots. Considerably larger applications could probably have been made without serious toxic effects. Sugar beets are apparently able to withstand heavy applications of borax without suffering any ill effect. The requirement of the crop for boron seems to be very high. Dennis and O'Brien (11) found that, compared to other crops, sugar beets possessed an unusual tolerance for high concentrations of H_3BO_3. The Gramineae absorb and require very small quantities of boron while the Leguminoseae require considerably more. The Chenopodiaceae, represented by the sugar beet, are near the top in the plant list in boron requirement. Analyses by Bertrand and DeWaal (3) of plants grown in the same soil show 75.6 mg boron per kg dry matter for sugar beets compared to less than 5 mg per kg for five different Gramineae examined. It seems logical that plants with a high boron requirement should be resistant to injury from high concentrations of the element.

The first symptoms of deficiency were observed on the youngest center leaves of the untreated plants about 2 months after the seeds were planted. Apparently there was enough boron in the sand and in the seeds to satisfy the needs of the seedlings for the first 2 months. An apparent restriction of growth of certain portions of the center leaves caused a curling and twisting that contrasted sharply with the larger normal leaves of plants which received an adequate application of borax at the start of the experiment. A breakdown of the petioles of the leaves was also observed early in the growth period. The darkening of the inner or concave side was accompanied by pronounced cross checks near the base of the petiole.

As the state of deficiency was prolonged, the darkened areas extended well into the midribs of larger leaves and could be observed in cases to affect the lateral veins or smaller branches of the leaf's circulatory system. The cross checking characteristic of the petioles seemed to be replaced by a linear checking or blackening as the brittle condition extended farther into the midribs.

Another striking condition observed with plants deficient in boron was the very dark green color of their leaves compared to the leaves of healthy plants. As daily additions of water were made, it was repeatedly observed that the boron-deficient plants were subject to rapid wilting. The blackening and checking of extreme cases gave way to a yellowed condition of midrib and veins in less severe cases, contrasting sharply with the somewhat whitish color of veins in healthy plants.

Schmidt (33) concluded that the unusually dark green color of the foliage of plants receiving insufficient boron and other associated conditions are caused by unregulated nitrate absorption. He observed that with less nitrate in the culture solution provided sugar beets, the deficiency symptoms were less severe, and reported similar results with varied nitrate levels in field experiments. Presumably, in the absence of boron, nitrate ions crowd into the cells until their concentration is sufficient to cause a breakdown of protoplasm and progressive necrosis. It is the apparent function of boron properly to regulate nitrogen intake and thus prevent this disorder.

In the fairly early stages of development of deficiency symptoms, the growing point and tips of the smaller heart leaves gradually turned black and died back until the entire growing point of the plant was killed. Closer examination in the advanced stages of the disorder showed that the blackened condition extended into the heart of the beet root. As the large outside leaves gradually yellowed and also died back, a stunted second growth of foliage was produced around the crown of the beet. The second-growth leaves remained green for a short time, probably as long as demands for boron were being partially supplied by the root and then turned black or yellow.

Brandenburg (4) showed by analysis that ash of sugar beets diseased with heart rot contained only 0.105 to 0.287% of H_3BO_3 compared to 0.36 to 0.442% in ash of healthy beets. This difference probably explains why second-growth leaves are short lived on diseased roots where there is no outside source of boron. The beet shown at the right of group 1 in Fig. 1 shows the manner in which recovery

growth is produced around the edge of the crown and not out of the dead heart of the beet.

After second-growth leaves of beets growing in the eight jars of the check series had attained their ultimate development, 4.8 mg of borax were applied to each of four jars, in order to determine if the plants even in this very advanced stage of deficiency might be revived or stimulated. Slowly, but positively, the plants in the four jars that were given borax put forth new leaves around the crown of the beet. So significant was the stimulation that the average yield of roots for these four jars was 22.8% greater than the average yield for the four jars never receiving any borax. As will be pointed out in results from another experiment, the recovery and additional yield would probably have been more pronounced if the application of boron had been made sooner. No positive symptoms of deficiency were observed on plants of other series receiving the applications of borax specified in Table 1.

Prominent symptoms of heart rot in sugar beets are shown in Fig. 1. By actual observation of the diseased and healthy roots, it was much more apparent than the pictures indicate that the fibrous root system had been materially restricted by the lack of boron. The

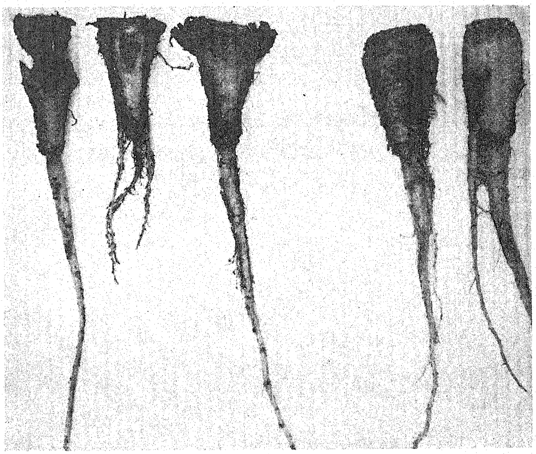

FIG. 1.—The beet roots on the left, grown in sand culture without any added boron, show marked deficiency symptoms, including necrotic areas, restricted fibrous root system, second or recovery foliage growth around crown, and blackening of tissue under the skin. The normal roots on the right were grown under adequate levels of boron.

fibrous roots of the deficient specimens were much shortened and the blackened tips seemed definitely to indicate that boron deficiency had the same effect on meristematic tissue of the roots as of the stems. The first part of the stem affected was observed to be the growing point and the relatively later observation of roots showed that the growing point likewise was first affected. O'Brien and Dennis (29) found that the fibrous roots of swedes grown in culture solutions did not develop if boron was lacking.

The cutaway section of one diseased specimen pictured shows a characteristic darkened layer underneath the skin that probably develops in even later stages than the physiological breakdown of the heart of the root. A more advanced stage of this brownish colored layer is shown at the extreme left in Fig. 1. The fluid or solvent condition in sand cultures might cause a more complete breakdown of the affected area than would occur under normal soil conditions of growth. The healthy specimens, shown at the right in Fig. 1, are representative of the shorter, more stocky roots developed under ample applications of boron.

If various rot organisms, such as *Phoma betae*, contributed to the breakdown of tissue and the development of other characteristic symptoms observed, it seems very evident that they were a secondary factor and that the primary or predisposing factor was boron deficiency. No signs of necrosis or abnormal coloration of tissue were detected in the beet roots properly supplied with this element. No efforts were intended or made to maintain a sterile medium for growth. The only known difference among culture series was in the content of boron.

FIELD-GROWN BEETS IN SAND CULTURES

The results of this experiment prove quite conclusively that boron was a factor of first importance in the development of heart rot in the beets selected from infested fields in the fall of 1937. All roots used in the experiment were affected to a severe extent with a diseased condition fitting closely the literature's description of "heart rot" or "boron deficiency". The degree of severity is noted in Table 2 for the 11 specimens used.

The condition of the half beets about one month after they were transplanted to sand cultures is shown in columns 3, 4, and 5 of Table 2.

Eight of the 11 halves receiving the small stimulating application of boron when transplanted October 17 had produced and maintained foliage free of obvious deficiency symptoms. Two of the other three halves had produced reasonably vigorous foliage but showed slight deficiency symptoms. The third failed to produce new leaves.

It was interesting to note, as was observed in the experiment with seedlings already described, that deficiency symptoms did not appear before about 10 days on the duplicate halves of beets receiving no borax at the outset. This observation seems to indicate again a limited available source of boron in the sand or in the root itself for the growing of leaves. Leaf development was insignificant after deficiency symptoms began to appear and the death of the whole crown was

TABLE 2.—*Response of diseased sugar beets to applications of boron.*

No. of jar	Diseased condition of beet when transplanted Oct. 17	Condition of foliage Nov. 12			"B" jars showing new leaves Nov. 15*	Condition of foliage Dec. 14		
		Vigorous; healthy	Medium vigor; deficiency symptoms	Stunted; severe deficiency symptoms		Vigorous; healthy	Medium vigor; deficiency symptoms	Stunted; severe deficiency symptoms
1	Very severe			No growth				Dead
1B†	Very severe			No growth				Dead
2	Medium			×	×	×		
2B	Medium	×				×		
3	Severe		×			×		
3B	Severe	×				×		
4	Severe			×	×	×		
4B	Severe	×				×		
5	Medium		×			×		
5B	Medium	×				×		
6	Severe			×	×	×		
6B	Severe		× No symptoms			×		
7	Very severe			×				Dead
7B	Very severe		×					Dead
8	Severe			×	×			Dead
8B	Severe	×				×		
9	Severe			×	×	×		
9B	Severe	×				×		
10	Medium			×	×	×		
10B	Medium		×			×		
11	Very severe			×	×	×		
11B	Very severe	×				×		

*Three days after application of boron to all jars.

†The half beets in jars identified by "B" received boron when transplanted to sand culture October 17, while the corresponding halves received none until November 12.

eminent on November 12, when the two representative specimens shown in Fig. 2 were photographed. The information presented in Table 2 shows that all of the 10 halves that started growth without added boron developed definite deficiency symptoms.

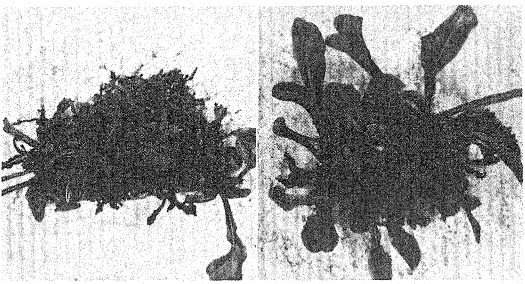

FIG. 2.—Abnormal foliage produced by halves of boron-deficient beets after 3 weeks in sand culture without added boron. Characteristic symptoms include blackening and death of numerous shoots around diseased crown, crinkled and distorted leaves, cross checking, and blackening of midrib and veins.

The amazing recovery of the sick specimens after application of 2.4 mg of $Na_2B_4O_7.10\ H_2O$ per jar was taken as further proof that boron was the controlling factor in the abnormal condition. Only 3 days after the boron was added, seven of the nine halves that ever recovered were showing vigorous green shoots to replace the dead or nearly dead foliage. The extent to which new leaves developed during the month following the application of boron is shown by Fig. 3.

The stimulating effect of the second application of boron to jars receiving a small application in the beginning was also noted. So small was the first application that its near depletion was reflected in the slowed growth of foliage on these halves of the beets. Based on the response observed, there seems little doubt that a continuous supply of the element is essential and that its role is, therefore, not merely catalytic.

The results of this experiment and the experiment with seedlings in sand cultures have indicated that when applications of boron are too long delayed after the plant shows starvation symptoms it will not revive as completely or make as large a growth as it would have if the borax had been applied before any deficiency symptons occurred.

SOLUBILITY OF BORAX IN SOIL

In the field application of borax it is well to consider residual effects or cumulative tendencies. In the case of sugar beets, a crop that withstands relatively large applications of borax without in-

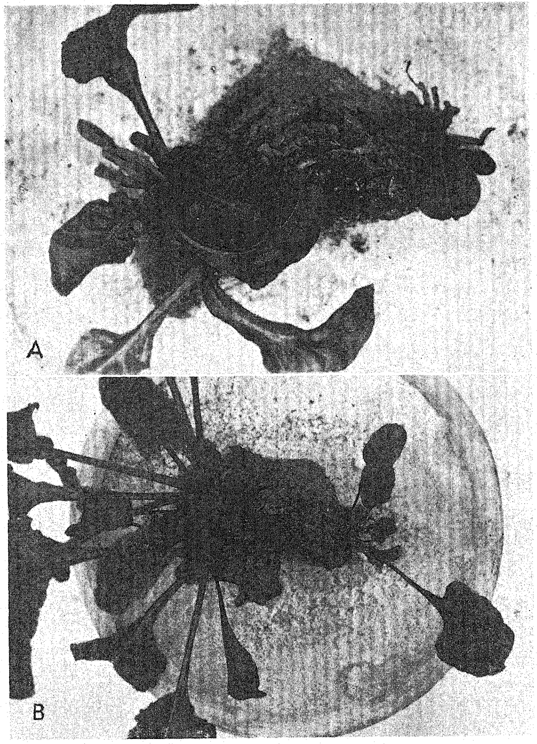

FIG. 3.—Mother beet, before and after addition of borax to nutrient solution. A, Characteristic "dead" crown showing advanced stages of dry heart rot. The twisted, distorted leaves and other symptoms suggest a serious effect of boron deficiency on the circulatory system of the petiole and midrib. Photograph taken Nov. 9. B, The same beet photographed Dec. 10 after 5 p.p.m. of $Na_2B_4O_7 \cdot 10H_2O$ had been added to the nutrient solution. Healthy leaves had replaced those shown in A.

jury, there seems little danger, with reasonable applications, of building up in the soil an undesirable reserve of boron. However, other

crops generally featured in a rotation on sugar beet soil are decidedly sensitive to boron and have to be more carefully considered. The cereal crops and grasses are especially sensitive and it has been shown that legumes require less boron than do sugar beets.

According to the results presented in Table 3, the production of two crops of sugar beets significantly reduced the quantity of boron which could be extracted from the soil by warm 0.02N HCl. This would indicate that a crop of sugar beets might be expected to remove a rather large part of the borax during the year when the application was made.

TABLE 3.—*The effect of cropping with sugar beets on the available B_2O_3 content of Napanee loam pot cultures.*

Treatment and extent of cropping	B_2O_3 in 25-gram samples of soil, av. of 4 pots, mg
Untreated, uncropped	0.065
Untreated, after two crops	0.053
Borax 76 mg per pot, after one crop	0.094
Borax 76 mg per pot, after two crops	0.067
Borax 304 mg per pot, after one crop	0.216
Borax 304 mg per pot, after two crops	0.172

To see whether or not the borax which remained in the pot cultures was soluble in water or was tied up in the soil in an insoluble form, the pots were subjected to leaching with distilled water after the second crop was removed. This was accomplished by keeping the pots flooded and catching the leachate from a hole at the bottom of the jar. As an average, 2,500 cc of leachate from the eight untreated Napanee soil cultures contained 0.85 mg borax, while the same volume of leachate from the eight pots which received 80 pounds of borax per acre contained 20.27 mg borax. In the case of the Thomas soil two successive 2,500-cc leachings were made on four untreated and four treated pots. From the untreated pots the two successive leachates contained as an average 1.126 mg and 0.86 mg borax, respectively, while from the treated pots the respective quantities of borax were 7.83 and 3.45 mg.

Although no attempts were made to leach these cultures completely, and while it is fully realized that the leaching was rather crudely done, the figures show that after 14 months in the soil the borax was still quite soluble in distilled water. Still greater quantities would no doubt have been removed if the leaching solution had been carbonic acid as is the case when field soils are leached with rain water. The effect of carbonic acid was shown by leaching tests conducted by Cook and Millar (9). They showed that a much greater quantity of boron was removed from soil by a carbonic acid solution than was removed by distilled water.

These data from the soil and leachate tests compare favorably with the results from extensive leaching tests conducted by Krugel, *et al.* (24) who showed that borax and boric acid applied with superphosphate were leached from the soil to the extent of 77.6 and 78.7%, respectively. They showed also that a normal beet crop removed

4 to 5 kg of borax per hectare when treated with 16 to 20 kg of borax per hectare.

Under such rapid absorption by the crop and the leaching to which humid soils are subjected, the possibility of boron accumulation to the point of toxicity seems less serious than might be supposed.

SUMMARY AND CONCLUSIONS

Sugar beet seedlings were grown in quartz sand cultures with and without borax. Symptoms of boron deficiency were carefully observed and studies were made regarding the recovery of beets afflicted with heart rot.

Field-grown mother beets showing heart rot symptoms were divided into halves and planted in quartz sand cultures, with and without borax applied at various times during the subsequent growth period. Observations were made on the types of leaves produced by these mother beets.

Soil and leachate tests were made to determine the extent of absorption of boron by sugar beets and the state of solubility of the boron remaining in the soil. This was done to throw some light on the possibility of boron accumulation in the soil. From the results of these experiments the following observations were made:

1. Seedlings grown in jars receiving no borax developed characteristic deficiency symptoms as follows:
   a. Blackening of tips of heart leaves, followed by death of growing portion of crown.
   b. Shortened, twisted petioles associated with crinkled condition of heart leaves and some of outer leaves.
   c. Abnormally dark green and thicker leaves, accompanied by more rapid wilting under drought conditions.
   d. Pimpled condition of petioles in early stages, followed by breakdown in form of cross and linear checking.
   e. Yellowing and eventual death of outer leaves, following the death of heart leaves.
   f. Stunted, second growth leaves following death of first leaves.
   g. Breakdown of heart of beet root.
   h. Darkened layer under skin of root and development of surface cankers in advanced stages.
   i. Restricted fibrous root system.
2. The available boron content of the quartz sand and the seed was adequate to prevent the appearance of deficiency symptoms for a period of two months after the seedlings were transplanted.
3. Yields of roots were increased as much as 80% by an application of 11.9 mg of borax per 5 kg of sand in divided applications.
4. Seedlings in advanced stages of heart rot definitely recovered upon the application of 4.9 mg of borax per pot.
5. Halves of field-grown mother beets planted in quartz sand cultures without borax produced stunted leaves with marked symptoms of boron starvation, whereas the corresponding halves which received like treatment but with borax added at the rate of 2 mg

per 1-gallon pot, produced a more abundant leaf growth free of deficiency symptoms.

6. Soil tests for available boron showed that a crop of sugar beets produced in pot cultures removes an appreciable quantity of boron from the soil.
7. By determining the quantity of B_2O_3 in leachates from pot cultures it was found that it was relatively easy to remove added borax from soils by leaching with distilled water even a year after the borax was applied.

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RESISTANCE OF CORN STRAINS TO THE LEAF APHID, *APHIS MAIDIS* FITCH[1]

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THE resistance or susceptibility of strains of corn to the corn-leaf aphid (*Aphis maidis* Fitch) has been observed at several locations in Illinois over a three-year period, 1937–39. Data presented here indicate the possibility of reducing injury caused by this insect through the use of resistant strains of the host.

Because efficient controls of the corn-leaf aphid can not be effected economically on a field basis by cultural practices, the use of insecticides, or by other methods useful in the case of a number of other insect pests, it is necessary to seek other solutions of the problem. One of the most promising methods of control involves the utilization of resistant strains now available and the breeding of new resistant strains of corn.

In Illinois, the corn-leaf aphid usually is present sometime during the growing season each year. This insect is not always present in sufficient numbers to cause serious loss and the type of damage usually is not spectacular. For that reason, damage by it is often not considered serious. However, under conditions of a light infestation the damage done by the leaf aphid is another factor that prevents maximum development of the corn plant. Heavy infestations sometimes result in the complete failure of grain development either by death of the plant or by destruction of the tassel which prevents pollination of the silks. In other cases ear-shoots may fail to develop on plants that have heavy infestations of aphids in the tassel, even though there are sufficient uninfested plants present to furnish pollen. This was observed in the hybrid performance test grown at Libertyville, Ill., in 1938 which was infested with leaf aphids. Data were obtained from five random plots of each of 60 different entries in this test. Only 1.2% of the entire plant population of the field was infested, but the plants that were infested had many aphids confined almost entirely to the tassels. This condition enabled normal pollen shedding from 98.8% of the plants in the field. Counts indicated that 48.1% of the infested plants were barren. It was estimated that only 1 to 2% of the uninfested plants were barren. These data indicate very strongly that aphids feeding in the tassel have a physiological effect upon the corn plant which retards or prevents development of the ear-shoot.

The corn-leaf aphid is an especially serious problem in the production of foundation seed stocks for use in the production of commercial

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hybrid seed corn. Inbred lines are normally weak, and a moderate infestation of aphids on a susceptible to moderately susceptible line may prevent satisfactory pollination of the ear parent, even though complete destruction of the pollen parent may not occur. For that reason considerable time has been devoted to a study of inbred lines, the results of which are presented here. A detailed description of the manner in which the corn-leaf aphid injures the host is omitted since this subject has been discussed in a number of publications dealing with this insect.

REVIEW OF LITERATURE

Host resistance as a means of reducing aphid injury has been used for several years with a number of crop plants and has been suggested as a control for several others.

The use of resistant vines as a control for the grape Phylloxera is a classic example of host resistance to insect injury. Bioletti (2)[3] and Twight (28) urged the use of resistant vines as the most satisfactory method of combating Phylloxera in California, because it is applicable to all conditions. Bonnet (5) reports that while the American grape species usually are considered resistant to Phylloxera the different species vary from practically complete| immunity to a susceptibility little less than that of *Vita vinifera*, the European species which is extremely susceptible. This variability among American vines in susceptibility has also been mentioned by Topi (27). Börner (6) has shown that several American vines are resistant to Phylloxera under conditions in Germany and suggests that in resistant-susceptible crosses resistance appears to act as a Mendelian dominant. According to Feytaud (12), the discovery of the resistance of American vines in 1869 eventually solved the problem of Phylloxera in Spain.

Since the discovery of immunity of Northern Spy apple to the woolly aphid many papers have been written on the use of host resistance as a means of combating damage caused by this insect. This insect is almost as widespread as the apple itself, and recommendations on the use of resistant stocks are numerous. Theobald (26), Staniland (25), Tydeman (29, 30), Le Pelley (18), Hatton (16), Massee (20), Greenslade, Massee, and Roach (15), and Crane, *et al.* (8) have all reported on resistance to this insect in England. Bremer (7) advocates the use of resistant stocks as a solution of the woolly aphid problem in Argentina, while Jancke (17) and Speyer (23) have reported on the resistance of apple varieties in Germany. Monzen (21) has published on the immunity of *Prunus prunifolia* and the susceptibility of *Prunus sieboldi* (toringo) in Japan, while Becker (1) has reported on experiments with woolly aphid resistance in this country.

Other outstanding cases of aphid resistance in a fruit crop have been reported by De Long and Jones (11), selections of Houghton gooseberry immune to the gooseberry aphid, Spinks (24), and Darrow, Waldo, and Schuster (9), varieties of strawberries resistant to the strawberry aphid, and Winter (31), the marked resistance of Herbert raspberry to *Amphorophora rubi*.

Reports of aphid resistance in field crops are less numerous, but sufficient cases have been reported to indicate that the use of resistant varieties of field crops may be of as much importance in the control of aphids as is the case with fruit crops. Davidson (10) reports that plants of *Vicia narbonensis* are highly resistant to *Aphis rumicis*, while in a study of 18 varieties of *Vicia faba* he found the grade

[3]Figures in parenthesis refer to "Literature Cited", p. 380.

of susceptibility ranged from 3 to 98%. He also indicates that resistance or susceptibility may be largely determined by genetic factors in the plant. Blanchard and Dudley (3) and Blanchard (4) have reported on the presence of plants of alfalfa that are highly resistant to the pea aphid, *Illinois pisi*. Searls (22) has shown that Onward and Perfection, varieties of canning peas, are resistant to the pea aphid, while Yellow Admiral is susceptible. He also presents data which indicate that resistance is associated with a yellowish green foliage color, while susceptibility is associated with dark green foliage color.

A review of the literature indicates that very little data have been published on aphid resistance in corn, but the papers that were found were in general agreement with data presented herein. Forbes (13) has reported experiments where attempts were made to rear the corn-leaf aphid on different host plants such as corn, wheat, grass, purslane, and apple. Gernert (14) reported on the aphis immunity of teosinte-corn hybrids. He found teosinte to be immune to the corn-leaf aphid, *Aphis maidis*, and the corn-root aphid, *Aphis maidi-radicis*, while the yellow dent corn used was very susceptible to both species. The F_1 plants showed the immunity of the teosinte parent, indicating that resistance was dominant in the first generation.

McColloch (19) has published on the resistance of varieties of open-pollinated corn to *Aphis maidis* in Kansas. He observed that the amount of aphid injury tended to increase with the lateness of the variety but that certain varieties having about the same maturity range varied rather widely in their aphid resistance. The observations of McColloch concerning the tendency for injury to increase with the lateness of the variety have been confirmed by the writers under conditions where the infestation of aphids did not develop before the tasseling period of early strains of corn. Lignification of the peduncle and other tassel parts tends to discourage aphid feeding although the plant otherwise might be susceptible. A reverse condition is also possible when natural enemies of the corn-leaf aphid reduce the infestation and thereby allow late tasseling varieties to escape severe damage.

Aphids as a group are very sensitive to the condition of the host plant as well as other environmental factors. These conditions must be recognized and considered in the determination of the resistance of a group of corn strains. Under the conditions of the present experiments it was believed that strain resistance is not the result of evasion, except perhaps in a few cases where records for only one year were available. Portions of these data have been studied with reference to the relationship between time of tasseling and percentage of plants infested. The coefficient of correlation computed from the data on 31 of the inbred lines was -0.21 ± 0.01, far from a marked value.

MATERIAL AND METHODS

A cooperative project for the study of insect resistance in corn and for the development of resistant strains was established in Illinois in 1937. Since that time annual plantings have been made of a large number of strains of corn for a study of injury by the major corn insect pests. Positive assurance of a sufficient infestation of the insects being studied can not always be determined in advance of planting time, and for that reason plantings have been made at several locations each season. The data presented here have been collected at Urbana and Oakwood in central Illinois and at McClure in extreme southern Illinois, approximately 240 miles south of Urbana.

At Urbana in 1937, data were obtained on a number of strains grown in single row plots replicated in four randomized blocks. Each plot consisted of 10 hills. Fifty-one inbred lines, 69 single crosses, 34 double crosses, and 66 open-pollinated varieties were available for study. In 1938 plantings were made at Urbana, Oakwood, and McClure. These plots consisted of duplicated and triplicated single row plots, 10 hills long. Aphid studies at these locations were confined mainly to inbred lines and single crosses. Urbana and McClure were the locations where plots were grown in 1939. Data were obtained at Urbana on aphid damage, but the infestation at McClure was not sufficient in the plots to permit differential readings.

The method of determining infested plants was by examination of recently emerged tassels for the presence of aphids. While the data presented here deal largely with the total percentage of plants infested, the severity of the infestation was determined on all infested plants and they were classified in three grades designated as light, medium, and heavy. The light class usually included plants upon which a rather small number of aphids were found, while the medium class included plants having a moderate infestation. The heavy class included plants with many aphids, and considerable damage was often evident on the upper leaves of the plant, as illustrated in Fig. 1. In most cases, there was a very close association between the degree of infestation and the total percentage of plants infested. A study has been made concerning this relationship on a portion of the data presented here. An injury index was determined by placing a penalty on plants having heavy damage. The percentage of plants showing heavy damage was multiplied by 3, while those classes with moderate and light infestations were multiplied by 2 and 1, respectively. These weighted percentages then were added together to obtain an injury index. The relationship between the injury index and the total percentage of plants infested was measured by computing the coefficient of correlation between them. The value of r was found to be 0.98 ± 0.006, and with this close association it is believed that the total percentage of plants infested is a fairly reliable measure of the resistance of a given strain of corn. A few exceptions were noted and will be discussed later in this paper. However, these exceptions were so few it is believed unnecessary to present the entire data showing severity of infestation.

RESULTS

The percentage of infested plants of yellow inbred lines is given in Table 1. The data obtained from white inbred lines are presented in Table 2. The intensity of the general infestation of aphids fluctuated rather widely with both location and season. In spite of this range in severity of infestation there is general agreement in the relative infestation of the different inbred lines in the different experiments. The coefficients of correlation indicate a reasonably close association of the relative ranking of the inbred lines grown at different locations. The r value computed from the data on 22 inbred lines grown at Urbana in 1937 and at Oakwood in 1938 was 0.75 ± 0.06, while an r value of 0.81 ± 0.06 was obtained for 14 inbred lines grown at Urbana in 1937 and at McClure in 1938.

The percentage of plants infested at Urbana in 1937 ranged from 0 to 90.0 for inbred 5356–3. The general level of infestation at Urbana in 1938 was higher than in 1937, ranging from 0 to 100% for five inbred lines. The maximum infestation of 67.5% for line 5120 at

McClure in 1938 indicates that the infestation there was less severe. Six of the inbred lines tested at McClure were free of any infestation. The infestation at Oakwood in 1938 was considered as very good for

FIG. 1.—A tassel of a plant of inbred 5356-2 showing a heavy infestation of corn-leaf aphids. The leaves have been killed and are void of green color. Pollen produced by this tassel became entangled in the honeydew secreted by the aphids and was not available for pollinating silks.

TABLE 1.—*Percentage of plants of yellow inbred lines infested with corn-leaf aphid.*

Inbred line	Origin	Urbana, 1937	Urbana, 1938	McClure, 1938	Oakwood, 1938	Average of 3 stations*	Average of 2 stations†
4226	Ill.	1.4	—	0.0	5.7	2.4	3.6
R4	Ill.	1.8	—	0.0	5.6	2.5	3.7
B2	Ind.	0.9	33.3	7.9	20.0	9.6	10.5
WF9	Ind.	7.8	—	22.8	16.2	15.6	12.0
K4	Kans.	4.0	—	11.7	43.2	19.6	23.6
L317	Iowa	5.2	68.2	7.7	65.6	26.2	35.4
Hy	Ill.	7.6	56.5	29.4	44.1	27.0	25.9
Kys	Kans.	3.5	100.0	12.9	71.9	29.4	37.7
Pr	Iowa	16.7	—	2.9	41.7	30.4	29.2
Tr	Ind.	15.3	—	10.5	78.8	35.2	47.1
38-11	Ind.	31.7	92.3	2.6	74.4	36.2	53.1
540	U. S.	19.6	78.9	23.3	100.0	47.6	59.9
701	Iowa	66.0	100.0	37.5	100.0	67.9	83.1
5120	Ill.	85.4	94.7	67.5	96.5	83.1	96.0
51	Ohio	0.0	—	—	0.0	—	0.0
A	Ill.	0.0	8.3	—	9.7	—	4.9
L9	Ind.	5.2	—	—	21.9	—	13.6
90	Ill.	0.0	—	—	42.3	—	21.2
66	Ind.	37.3	—	—	62.0	—	49.7
5680	Ill.	37.1	—	—	63.2	—	50.2
5953	Ill.	68.4	—	—	94.0	—	80.2
5325-4	Ill.	62.6	—	—	100.0	—	81.4
K	Ill.	0.0	18.8	—	—	—	—
CC2	Wis.	0.0	—	—	—	—	—
5313-2-5	Ill.	0.9	—	—	—	—	—
5676	Ill.	1.0	—	—	—	—	—
2204	Ill.	2.9	—	—	—	—	—
5317-2	Ill.	4.9	—	—	—	—	—
5316-1-2	Ill.	6.5	—	—	—	—	—
CC6	Wis.	7.6	—	—	—	—	—
5675	Ill.	7.8	—	25.6	—	—	—
4211	Ill.	12.8	—	24.0	—	—	—
2203	Ill.	22.6	—	—	—	—	—
5678	Ill.	23.5	—	65.2	—	—	—
I198	Iowa	36.0	—	—	—	—	—
10	Ohio	45.0	—	—	—	—	—
5679	Ill.	46.7	—	—	—	—	—
5955	Ill.	57.0	—	—	—	—	—
4451	Ill.	72.6	—	—	—	—	—
5378-2	Ill.	81.8	—	—	—	—	—
5356-2	Ill.	85.8	—	—	—	—	—
5356-3	Ill.	90.0	—	—	—	—	—
56	Ohio	—	3.7	16.7	6.1	—	—
67	Ohio	—	44.4	0.0	—	—	—
28	Ohio	—	63.6	38.9	—	—	—
07	Ohio	—	100.0	22.8	—	—	—
02	Ohio	—	100.0	58.8	100.0	—	—
K 166	Kans.	—	89.3	0.0	—	—	—
15-6	Ohio	—	—	0.0	—	—	—
187-2	U. S.	—	—	0.0	—	—	—
I159	Iowa	—	—	15.4	—	—	—
I205	Iowa	—	—	19.4	—	—	—

*Urbana, Ill., 1937; Oakwood, Ill., 1938; McClure, Ill., 1938.
†Urbana, Ill., 1937, and Oakwood, Ill., 1938.

TABLE 1.—*Concluded.*

Inbred line	Origin	Urbana, 1937	Urbana, 1938	McClure, 1938	Oakwood, 1938	Average of 3 stations*	Average of 2 stations†
4–8	U. S.	—	—	53.0	97.2	—	—
CCl	Wis.	—	—	—	0.0	—	—
Fe	Ind.	—	—	—	0.0	—	—
C2	Ind.	—	—	—	10.5	—	—
KR100–5–1	Ind.	—	—	—	15.1	—	—
H6	Ind.	—	—	—	15.4	—	—
5110	Ill.	—	—	—	44.8	—	—
84	Ohio	—	100.0	—	88.9	—	—
Averages		27.3	67.8	20.6	48.0		
Range		0–90.0	3.7–100.0	0–67.5	0–100.0		

TABLE 2.—*Percentage of plants of white inbred lines infested with corn-leaf aphid, Urbana, Ill., 1938–39, and McClure, Ill., 1938.*

Inbred line	Origin of line	Percentage of plants infested			2-year average*	3-year average†
		Urbana, 1938	Urbana, 1939	McClure, 1938		
2075	Ky.	0.0	0.0	0.0	0.0	0.0
24	U. S.	2.9	8.0	—	5.5	—
50	Ky.	1.9	20.0	28.9	11.0	16.9
JC 33	Ind.	0.7	40.4	13.7	20.6	18.3
B103	Mo.	10.0	68.0	0.0	39.0	26.0
43	U. S.	14.3	69.7	—	42.0	—
13	Ky.	9.0	79.2	—	44.1	—
PS 6	Kans.	22.4	79.5	22.7	51.0	41.5
30A	Ky.	24.5	78.1	67.9	51.3	56.8
28	Ky.	23.1	100.0	—	61.6	—
62	U. S.	32.9	100.0	—	66.5	—
27	Ky.	37.8	100.0	34.2	68.9	57.3
11b	U. S.	39.6	100.0	42.4	69.8	60.7
21	Ky.	64.7	78.6	30.0	71.7	57.8
61	U. S.	51.6	100.0	—	75.8	—
39	Ky.	64.4	88.0	14.3	76.2	55.6
PS 22	Kans.	55.5	100.0	34.3	77.8	63.3
11a	U. S.	59.2	100.0	—	79.6	—
41	U. S.	63.8	96.7	—	80.3	—
23	U. S.	76.2	84.4	—	80.4	—
73	Ky.	71.4	96.0	—	83.7	—
122	Ky.	75.0	100.0	—	87.5	—
56	Ky.	80.9	100.0	—	90.5	—
89	Ky.	100.0	100.0	—	100.0	—
Averages		40.9	78.6	26.2		
Range		0–100.0	0–100.0	0–67.9		

*Urbana, 1938–39.
†Urbana, 1938–39; and McClure, 1938.

obtaining differential resistance data. The range in infestation was from 0 for inbreds 51, CCl, and Fe to 100% for inbreds 540, 701, 5325–4, and 02.

TABLE 1.—*Percentage of plants of yellow inbred lines infested with corn-leaf aphid.*

Inbred line	Origin	Urbana, 1937	Urbana, 1938	McClure, 1938	Oakwood, 1938	Average of 3 stations*	Average of 2 stations†
4226	Ill.	1.4	—	0.0	5.7	2.4	3.6
R4	Ill.	1.8	—	0.0	5.6	2.5	3.7
B2	Ind.	0.9	33.3	7.9	20.0	9.6	10.5
WF9	Ind.	7.8	—	22.8	16.2	15.6	12.0
K4	Kans.	4.0	—	11.7	43.2	19.6	23.6
L317	Iowa	5.2	68.2	7.7	65.6	26.2	35.4
Hy	Ill.	7.6	56.5	29.4	44.1	27.0	25.9
Kys	Kans.	3.5	100.0	12.9	71.9	29.4	37.7
Pr	Iowa	16.7	—	2.9	41.7	30.4	29.2
Tr	Ind.	15.3	—	10.5	78.8	35.2	47.1
38–11	Ind.	31.7	92.3	2.6	74.4	36.2	53.1
540	U. S.	19.6	78.9	23.3	100.0	47.6	59.9
701	Iowa	66.0	100.0	37.5	100.0	67.9	83.1
5120	Ill.	85.4	94.7	67.5	96.5	83.1	96.0
51	Ohio	0.0	—	—	0.0	—	0.0
A	Ill.	0.0	8.3	—	9.7	—	4.9
L9	Ind.	5.2	—	—	21.9	—	13.6
90	Ill.	0.0	—	—	42.3	—	21.2
66	Ind.	37.3	—	—	62.0	—	49.7
5680	Ill.	37.1	—	—	63.2	—	50.2
5953	Ill.	68.4	—	—	94.0	—	80.2
5325–4	Ill.	62.6	—	—	100.0	—	81.4
K	Ill.	0.0	18.8	—	—	—	—
CC2	Wis.	0.0	—	—	—	—	—
5313–2–5	Ill.	0.9	—	—	—	—	—
5676	Ill.	1.0	—	—	—	—	—
2204	Ill.	2.9	—	—	—	—	—
5317–2	Ill.	4.9	—	—	—	—	—
5316–1–2	Ill.	6.5	—	—	—	—	—
CC6	Wis.	7.6	—	—	—	—	—
5675	Ill.	7.8	—	25.6	—	—	—
4211	Ill.	12.8	—	24.0	—	—	—
2203	Ill.	22.6	—	—	—	—	—
5678	Ill.	23.5	—	65.2	—	—	—
I198	Iowa	36.0	—	—	—	—	—
10	Ohio	45.0	—	—	—	—	—
5679	Ill.	46.7	—	—	—	—	—
5955	Ill.	57.0	—	—	—	—	—
4451	Ill.	72.6	—	—	—	—	—
5378–2	Ill.	81.8	—	—	—	—	—
5356–2	Ill.	85.8	—	—	—	—	—
5356–3	Ill.	90.0	—	—	—	—	—
56	Ohio	—	3.7	16.7	6.1	—	—
67	Ohio	—	44.4	0.0	—	—	—
28	Ohio	—	63.6	38.9	—	—	—
07	Ohio	—	100.0	22.8	—	—	—
02	Ohio	—	100.0	58.8	100.0	—	—
K 166	Kans.	—	89.3	0.0	—	—	—
15–6	Ohio	—	—	0.0	—	—	—
187–2	U. S.	—	—	0.0	—	—	—
I159	Iowa	—	—	15.4	—	—	—
I205	Iowa	—	—	19.4	—	—	—

*Urbana, Ill., 1937; Oakwood, Ill., 1938; McClure, Ill., 1938.
†Urbana, Ill., 1937, and Oakwood, Ill., 1938.

TABLE 1.—*Concluded.*

Inbred line	Origin	Urbana, 1937	Urbana, 1938	McClure, 1938	Oakwood, 1938	Average of 3 stations*	Average of 2 stations†
4–8	U. S.	—	—	53.0	97.2	—	—
CCl	Wis.	—	—	—	0.0	—	—
Fe	Ind.	—	—	—	0.0	—	—
C2	Ind.	—	—	—	10.5	—	—
KR100-5-1	Ind.	—	—	—	15.1	—	—
H6	Ind.	—	—	—	15.4	—	—
5110	Ill.	—	—	—	44.8	—	—
84	Ohio	—	100.0	—	88.9	—	—
Averages		27.3	67.8	20.6	48.0		
Range		0–90.0	3.7–100.0	0–67.5	0–100.0		

TABLE 2.—*Percentage of plants of white inbred lines infested with corn-leaf aphid, Urbana, Ill., 1938–39, and McClure, Ill., 1938.*

Inbred line	Origin of line	Percentage of plants infested			2-year average*	3-year average†
		Urbana, 1938	Urbana, 1939	McClure, 1938		
2075	Ky.	0.0	0.0	0.0	0.0	0.0
24	U. S.	2.9	8.0	—	5.5	—
50	Ky.	1.9	20.0	28.9	11.0	16.9
JC 33	Ind.	0.7	40.4	13.7	20.6	18.3
B103	Mo.	10.0	68.0	0.0	39.0	26.0
43	U. S.	14.3	69.7	—	42.0	—
13	Ky.	9.0	79.2	—	44.1	—
PS 6	Kans.	22.4	79.5	22.7	51.0	41.5
30A	Ky.	24.5	78.1	67.9	51.3	56.8
28	Ky.	23.1	100.0	—	61.6	—
62	U. S.	32.9	100.0	—	66.5	—
27	Ky.	37.8	100.0	34.2	68.9	57.3
11b	U. S.	39.6	100.0	42.4	69.8	60.7
21	Ky.	64.7	78.6	30.0	71.7	57.8
61	U. S.	51.6	100.0	—	75.8	—
39	Ky.	64.4	88.0	14.3	76.2	55.6
PS 22	Kans.	55.5	100.0	34.3	77.8	63.3
11a	U. S.	59.2	100.0	—	79.6	—
41	U. S.	63.8	96.7	—	80.3	—
23	U. S.	76.2	84.4	—	80.4	—
73	Ky.	71.4	96.0	—	83.7	—
122	Ky.	75.0	100.0	—	87.5	—
56	Ky.	80.9	100.0	—	90.5	—
89	Ky.	100.0	100.0	—	100.0	—
Averages		40.9	78.6	26.2		
Range		0–100.0	0–100.0	0–67.9		

*Urbana, 1938–39.
†Urbana, 1938–39; and McClure, 1938.

obtaining differential resistance data. The range in infestation was from 0 for inbreds 51, CCl, and Fe to 100% for inbreds 540, 701, 5325-4, and 02.

Many of the inbred lines were not grown during the entire period of these tests and for that reason dependable averages are limited to those lines grown in more than one year. Attempts were made to observe the resistance of lines of the most agronomic importance in the Corn Belt hybrid corn programs, hence less valuable lines have been eliminated from time to time and new and promising lines have been added. However, some of the older standard lines have been in most of the tests and a 3-station year average is shown for 14 inbred lines. A 2-year average is presented for 22 inbred lines.

White inbred lines grown in the white corn breeding nursery at Urbana were made available for aphid studies through the courtesy of Wayne H. Freeman of the Illinois Agricultural Experiment Station. Data on aphid resistance were obtained at Urbana on 24 of these inbred lines during 1938 and 1939 and on 11 of the same lines at McClure in 1938.

The general level of infestation at Urbana was higher in the white inbred nursery in 1939 than in 1938, but the more resistant inbreds were relatively free of aphids during both seasons, while the more susceptible strains were heavily infested both years. The level of infestation at McClure was not as high as at Urbana. Kentucky inbred 2075 was free of aphids at each location. The range in infestation at Urbana was from 0 to 100% during both seasons, while the range at McClure was from 0 to 67.9%. From the data shown in Table 2 it is evident that such inbred lines as Kentucky 2075 and U. S. 24 have rather high resistance, while Kentucky inbreds 122, 56, and 89 are susceptible.

Variations in aphid resistance and susceptibility have been sufficiently great among inbred lines that it was thought desirable to obtain data on the reaction of some of the lines in hybrid combinations. Table 3 presents data which indicate that aphid resistance is inherited. Sixteen inbred lines varying in their resistance to aphids were crossed with inbred 38–11, a moderately susceptible line in most tests although only 2.6% of the plants were infested in this test at McClure. Plots of the F_1 plants were grown at McClure in 1938, under aphid conditions. In general, the aphid resistance of the single crosses paralleled the aphid resistance of the inbred lines crossed with 38–11. Quartile averages were made of the percentage of plants infested in the inbred lines and the corresponding single crosses. The quartile averages for the single crosses were 8.4, 12.7, 22.3, and 43.0% of the plants infested as compared with 6.0, 9.9, 23.9 and 47.0% infested for the corresponding inbred lines crossed with 38–11.

The transmission of aphid reaction by inbred lines to their single crosses was studied further in another experiment. Six inbred lines, L317, 38–11, Hy, 540, R4, and WF9, were crossed in all possible combinations and the resulting single crosses, 15 in number, were tested under conditions of an aphid infestation at McClure in 1938. Data from this experiment are presented in Table 4.

The data in Table 4 indicate marked differences among the lines in the transmission of resistance or susceptibility to their hybrids. Single crosses involving WF9 were uniformly susceptible. Those involving Hy were resistant, except for the combination with WF9.

TABLE 3.—*Percentage of plants infested with corn-leaf aphid, crosses involving inbred 38–11, McClure, Ill., 1938.*

F_1 single cross	Total infested, %	Quartile average, %	Inbred line*	Total infested, %	Quartile average, %
38–11 ×Kys...	2.6	8.4	Kys	12.9	6.0
38–11 ×L317..	4.9		L317	7.7	
38–11 ×187–2	7.3		187–2	3.2	
38–11 ×R4....	10.8		R4	0.0	
38–11 ×07....	11.4	12.7	07	22.8	9.9
38–11 ×67....	12.2		67	0.0	
38–11 ×56....	13.6		56	16.7	
38–11 ×15–6..	13.6		15–6	0.0	
38–11 ×540...	15.8	22.3	540	23.3	23.9
38–11 ×K166	20.0		K166	0.0	
38–11 ×4–8...	25.6		4–8	53.0	
38–11 ×I205...	29.7		I 205	19.4	
38–11 ×WF9..	31.5	43.0	WF9	22.8	47.0
38–11 ×5120	37.2		5120	67.5	
38–11 ×28....	39.0		28	38.9	
38–11 ×02....	64.3		02	58.8	
Average....	21.2			31.5	

*38–11 had 2.6 of the plants infested in this experiment.

Line 38–11 seemed to have relatively little influence upon its hybrids, their response apparently being more largely determined by the other parents. A similar situation was obtained among the single crosses listed in Table 3.

TABLE 4.—*Percentage of plants infested by the corn-leaf aphid, six inbred lines tested in all possible single cross combinations at McClure, Ill., 1938**

Inbred line	L317	38–11	Hy	540	R4	WF9
L317....................	—	4.9	5.1	13.7	4.9	23.1
38–11....................	4.9	—	7.3	15.8	10.8	31.5
Hy....................	5.1	7.3	—	7.7	4.8	48.9
540....................	13.7	15.8	7.7	—	22.3	27.5
R4....................	4.9	10.8	4.8	22.3	—	69.4
WF9....................	23.1	31.5	48.9	27.5	69.4	—
Average..................	10.3	14.1	14.8	17.4	22.4	40.1
Percentage of plants infested.	7.7	2.6	29.4	23.3	0.0	22.8

*Seed of the single crosses used in this experiment was supplied by G. H. Stringfield.

The data presented in Tables 3 and 4 indicate without question that resistance is inherited. There are indications that the response of the hybrids may in some cases be explained best on the assumption of complementary factors contributed by the two parents. However, it is recognized that these data are inadequate and that aphids are especially sensitive to the conditions of the host plant and other environmental factors, and for these reasons it does not seem advisable to draw further conclusions.

Further study is also needed concerning the method of measuring resistance. In general, the total percentage of plants infested seems to be a rather satisfactory indicator of resistance. This is especially true when the data are supplemented by classifying the intensity of the infestation on the individual plants of a population. In most cases, where plants have a high total percentage of infestation, they will also have a relatively high percentage of plants with large aphid populations. Inbred 701 (or 540) is an exception to this condition in that usually many plants are infested but seldom is the infestation heavy enough to interfere with pollination.

It was observed that some of the inbreds were not uniform in their resistance or susceptibility. Some of the lines tested appeared to consist of a mixture of reasonably homozygous resistant and susceptible plants with relatively few heterozygous individuals. The seed of the inbred lines used in these experiments consisted in many cases of bulk selfed seed (obtained by mixing the seed of many selfed ears) carried by the experiment stations. Apparently in some cases selfed seed of the lines had been mixed while still segregating for resistance and had since been carried by a procedure which involved the planting of this bulk seed, the selfing of numerous plants, and the mixing each season of the selfed seed obtained.

SUMMARY

Data presented here indicate the possibility of reducing injury caused by *Aphis maidis* through the use of host resistance.

The corn-leaf aphid is an especially serious problem in the production of certain foundation seed stocks which are for use in the production of commercial hybrid seed corn.

The infestation was determined by an examination of recently emerged tassels for the presence of aphids. Although the severity of the infestations was measured by classifying all infested plants in one of three infestation classes, in general the total percentage of infestation was considered as a reliable indicator of the relative resistance or susceptibility.

Data are presented from many yellow and white inbred lines as well as from a sufficient number of single crosses to indicate that resistance to this insect is a heritable character.

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EFFECT OF AWNS ON KERNEL WEIGHT, TEST WEIGHT, AND YIELD OF WHEAT[1]

B. B. BAYLES AND C. A. SUNESON[2]

THE coordinated wheat improvement experiments at 17 stations in eight western states (3),[3] have offered an excellent opportunity for a study of the performance of awned and awnless wheats under very diverse environments. The problem is of both theoretical and practical interest. Many of the previous experiments with wheat to determine the influence of awns on yield and kernel weight have not been conclusive and no attempt has been made to test similar material at more than one location. In general, awned plants have tended to produce heavier kernels and a higher weight of grain per plant, although this has not always been the case. Clark and Quisenberry (1) and Lamb (2) have reviewed the literature on the effect of awns in wheat.

The data on the effect of awns presented here were obtained from composite populations of awned and awnleted segregates from two crosses, one between two winter varieties and the other between two spring varieties. Material for another method of comparing awned and awnless wheats is being developed, but results will not be available for several years. This material is being produced by repeated backcrossing of awnless segregates with the awned parent and awned segregates with the awnless parent. It is planned to continue backcrossing until types similar to the two parents in all genetic characteristics except presence or absence of awns have been obtained. These should be better suited for further studies on the influence of awns on the development of the wheat kernel.

MATERIAL AND METHODS

In the experiments reported here composites of awned and of awnless or awnleted segregates from two crosses involving parents of considerable prominence in the western states were studied. Plants in the F_2 generation of the cross, Triplet ×Oro, grown at Moscow, Idaho, in 1933 were classified as awned, heterozygous awnleted, and awnleted. Samples totaling about 2 pounds each of seed of the awned and awnleted segregates were composited and planted at Pendleton, Ore., in the fall of 1933. Seed from this crop was distributed for seeding uniform yield trials in the fall of 1934, the first yields thus being obtained in 1935 on the F_4 generation.

A smaller F_2 population of the second cross, Baart×Onas, was grown at Aberdeen, Idaho, in 1933. Plants were separated into three classes, *viz.*, awned, heterozygous awnleted, and homozygous awnless or awnleted, and the F_3 generation of each class was grown during the winter at Tucson, Ariz., where the homozygous plants were again separated from the segregating population and added

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[3]Figures in parenthesis refer to "Literature Cited", p. 388.

to the respective true breeding composites. The F_4 generation of the awned and awnleted composites was grown at Aberdeen, Idaho, in 1934 from spring seeding. The seed stocks were rogued carefully and then grown at Tucson during the winter of 1934–35 and the resulting seed sown at Aberdeen, Idaho, in the spring of 1935. The F_7 and later generations were grown in uniform yield trials at several stations beginning in 1936.

Successive yield trials have represented a progressively smaller random portion of the original hybrid population in advancing stages of homozygosity. Seed for the subsequent tests of Triplet×Oro at all cooperating stations has been supplied from seed plots at Pendleton, Ore., and Pullman, Wash., and seed of Baart×Onas was produced at Pullman and at Aberdeen, Idaho. The yields and other data have been obtained from paired adjacent plots of awned and awnleted types included in uniform varietal nurseries from which yields and other agronomic data are summarized annually (3). Each nursery consisted of three 3-row plots with the rows 16 feet long and 12 inches apart. The center row only in each plot was harvested for yield. Planting rates varied according to commercial practice in each section. The one exception to the above procedure was in 1939 when tests of the Baart×Onas composites were made in nurseries consisting of five pairs of single 16-foot rows protected on the flanks by guard rows.

EXPERIMENTAL RESULTS

EFFECT OF AWN ON KERNEL WEIGHT

Comparative kernel weights from awnleted and awned plants for the 4-year period 1936–39 are shown in Table 1. These weights were obtained from random samples of whole kernels, consisting of five 100-kernel samples of each lot in 1936, three 1,000-kernel samples in 1937, and three 200-kernel samples in 1938 and 1939. Standard errors were about the same in each season. Some of the annual differences in kernel weights may be due to variations in moisture at the time of weighing, but all comparable pairs were stored together and weighed at the same time.

An average kernel weight difference of 0.8 milligram, or 2.6%, in favor of awned plants was obtained from the 36 comparable lots in the Triplet×Oro cross. Awned samples had a greater weight in 27 of the 36 tests. This distribution tested by the binomial method gives odds for a difference in favor of the awned type greater than 99 to 1. Since the binomial method of determining odds is easy to apply and since it is suited to comparisons of this kind, it is used throughout this paper. In this method magnitude of differences is ignored. Ties were divided equally between the two groups or if an odd number occurred, one was omitted.

Data are available from 42 station-year comparisons of the Baart× Onas segregates grown at non-irrigated and irrigated stations. Parents and hybrids in this instance represent true spring types of white wheat, whereas the Triplet×Oro cross combined two red winter wheats. Spring wheats, because of a shorter growing period and later summer maturity, commonly suffer more from high temperatures and drought than do winter wheats. The average kernel weight of the awned composite of Baart×Onas was 1.7 milligrams, or 4.3%, greater than that of the awnleted composite. The awned composite

TABLE I.—*Kernel weights of composited awnleted and awned segregates.*

Station where grown	Weight per kernel, mgms									
	Awnleted composite					Awned composite				
	1936	1937	1938	1939	Av.	1936	1937	1938	1939	Av.
					Triplet × Oro					
Moro, Ore.	20.4	31.9	21.8	25.7	25.0	21.8	34.8	22.1	26.1	26.2
Pendleton, Ore.	32.5	32.3	30.1	28.9	31.0	35.0	33.7	31.3	30.2	32.6
Union, Ore.	—	—	34.6	33.8	34.2	—	—	34.2	35.6	34.9
Pullman, Wash.	33.1	31.9	34.9	31.1	32.8	34.5	31.8	34.9	31.1	33.1
Walla Walla, Wash.	32.6	—	33.4	34.6	33.5	33.4	—	33.2	34.9	33.8
Pomeroy, Wash.	24.2	—	21.8	28.7	24.9	24.3	—	22.4	29.7	25.5
Lind, Wash.	—	—	27.8	27.7	27.8	—	—	28.6	28.0	28.3
Moscow, Idaho	—	35.2	34.4	—	34.8	—	37.1	33.7	—	35.4
Sandpoint, Idaho	—	37.3	31.3	34.3	34.3	—	39.8	31.7	36.2	35.9
Tetonia, Idaho	—	34.5	31.3	30.8	32.2	—	39.7	32.2	30.2	34.0
Rockland, Idaho	—	—	28.6	24.2	26.4	—	—	28.8	27.1	28.0
Clarkston, Utah	—	—	39.7	27.9	33.8	—	—	35.1	31.2	33.2
Davis, Calif.	—	—	38.7	33.0	35.9	—	—	38.8	31.9	35.4
Average	28.6	33.9	31.4	30.1	31.0	29.8	36.2	31.3	31.0	31.8
Times superior	0	1	4	2	7*	5	5	8	9	27*
					Baart × Onas					
Moro, Ore.	18.0	35.2	26.5	25.7	26.4	20.6	39.6	28.5	27.4	29.0
Pendleton, Ore.	39.0	42.1	40.0	38.6	39.9	38.9	46.1	40.3	39.8	41.3
Union, Ore.	—	45.5	42.7	—	44.1	—	41.9	45.8	—	43.9
Pullman, Wash.	40.5	42.9	39.3	38.2	40.2	45.0	42.5	39.6	40.9	42.0
Walla Walla, Wash.	—	40.7	39.3	—	40.0	—	42.6	40.3	—	41.5
Pomeroy, Wash.	29.8	33.2	30.4	—	31.1	30.9	36.3	31.9	—	33.0
Lind, Wash.	—	39.6	38.1	—	38.9	—	40.7	40.2	—	40.5
Moscow, Idaho	39.8	39.1	39.6	—	39.5	43.3	38.6	41.6	—	41.2
Sandpoint, Idaho	—	48.8	36.2	—	42.5	—	47.4	36.3	—	41.9
Tetonia, Idaho	—	37.8	—	—	37.8	—	43.3	—	—	43.3
Davis, Calif.	—	—	45.0	35.5	40.3	—	—	48.2	35.6	41.9
Bozeman, Mont.†	35.0	50.4	43.1	—	42.8	35.6	51.7	45.2	—	44.2
Aberdeen, Idaho†	48.0	48.0	46.8	45.7	47.1	48.2	52.6	48.0	48.0	49.2
Logan, Utah†	—	—	38.6	41.6	40.1	—	—	39.8	43.6	41.7
Hesperus, Colo.†	—	49.6	40.5	—	45.1	—	50.8	43.2	—	47.0
Prosser, Wash.†	—	—	51.3	—	51.3	—	—	51.2	—	51.2
Tucson, Ariz.†	—	—	—	39.2	39.2	—	—	—	40.5	40.5
Average	35.7	42.5	39.8	37.8	39.6	37.5	44.2	41.3	39.4	41.3
Times superior	1	4	1	0	6*	6	9	14	7	36*

*Times superior for individual station years.
†Grown under irrigation.

had a greater kernel weight in 36 of the 42 tests. This distribution tested by the binomial method gives odds for a difference in favor of the awned composite greater than 99 to 1.

Data are not extensive enough to establish significant differences between the awned and awnleted composites at individual stations, but by grouping low rainfall stations such as Moro and Lind; intermediate rainfall stations such as Pendleton, Pullman, and Moscow; high rainfall stations such as Union; and irrigated stations and, also by combining results for the two hybrid populations, the number of tests is adequate for comparisons between different environments. These comparisons do not show any association in kernel weight between environment and awn type in the material.

EFFECT OF AWN ON TEST WEIGHT

Test weight, in pounds per bushel, is an important grain grading factor and also is associated with flour yield. It is influenced not only by kernel weight but also by kernel characters such as shape, size, plumpness, and density of the kernels, width, and depth of crease, and extent of brush. Despite the interest in this factor, no reference to its relation to awns has been found in the literature.

Comparative test weights of grain for 31 station years for the Triplet×Oro cross and for 35 station years for the Baart×Onas cross are shown in Table 2. In the Triplet×Oro cross the average difference in favor of the awned composite was 0.7 pound per bushel and in no case did the test weight of the awnleted composite exceed that of the awned composite. The weights were equal in only 3 of the 31 comparisons. In the Baart×Onas cross the average difference was 1 pound in favor of the awned composite and in only 3 of the 35 comparisons did the test weight of the awnleted composite equal or exceed that of the awned composite. A very positive advantage for awned types was obtained in both crosses and the differences were evident over the entire environmental range studied.

EFFECT OF AWN ON YIELD

Yields in bushels per acre for the awnleted and the awned composite from each of the two crosses are given in Table 3. The composites of the awnleted and the awned segregates from the Triplet×Oro cross averaged 39.4 and 39.2 bushels per acre, respectively, for the 48 station years. The awnleted composite gave the higher yield in 27 tests, the awned composite in 17 tests, and the yields were equal in 4 tests. Testing the distribution by the binomial method the odds are only 6 to 1 and the difference is not significant.

Yields of the awnleted and awned composites from the Baart×Onas cross were very similar in 1936 and 1937. In 1938, the awned composite gave the higher yield at each of the 15 stations, averaging 49.8 bushels compared to 43.1 bushels for the awnleted composite. In 1939, the awned composite gave the higher yield at six of the seven stations and averaged 47.9 bushels compared to 45.3 bushels for the awnleted composite. Considering the 50 station years, the awned composite was higher at 38 and averaged 45.8 bushels, whereas the awnleted composite was higher at only 11 and averaged 43.3 bushels. They were equal at one station one year. This distribution tested by the binomial method gives odds greater than 99 to 1 that the difference is significant.

TABLE 2.—*Test weights of composites of awnleted and awned segregates.*

Station where grown	Test weight in pounds per bushel											
	Awnleted composite						Awned composite					
	1935	1936	1937	1938	1939	Av.	1935	1936	1937	1938	1939	Av.
Triplet × Oro												
Pullman	61.9	62.7	64.0	63.5	61.1	62.6	62.2	63.2	64.0	63.8	62.2	63.1
Walla Walla	60.4	61.0	—	60.6	60.5	60.6	60.8	61.7	—	61.3	61.2	61.3
Pomeroy	62.9	59.3	62.5	60.5	61.9	61.4	63.1	60.2	63.0	60.5	62.6	61.9
Lind	61.5	—	—	60.5	59.0	60.3	63.0	—	—	61.0	59.5	61.2
Moro	—	55.2	60.0	58.0	59.5	58.2	—	56.5	61.5	58.0	60.5	59.1
Pendleton	62.0	62.5	61.8	62.0	61.0	61.9	63.2	63.3	63.0	62.8	61.8	62.8
Moscow	62.0	—	—	61.9	62.0	62.0	62.4	—	—	62.2	62.2	62.3
Clarkston	—	—	—	62.0	—	62.0	—	—	—	62.9	—	62.9
Davis	—	—	—	—	61.7	61.7	—	—	—	—	62.3	62.3
Average	61.8	60.1	62.1	61.1	60.8	61.1	62.5	61.0	62.9	61.6	61.5	61.8
Times superior	0	0	0	1	0	1*	6	5	3	7	8	29*
Baart × Onas												
Pendleton	—	60.0	61.7	61.1	—	60.9	—	61.2	62.3	62.2	—	61.9
Moro	—	46.5	58.0	54.5	54.0	53.3	—	50.0	59.0	56.0	56.0	55.3
Moscow	—	—	—	59.0	—	59.0	—	—	—	60.0	—	60.0
Davis	—	—	—	61.0	59.6	60.3	—	—	—	60.6	60.7	60.7
Pullman	—	62.0	59.7	61.9	61.3	61.2	—	63.1	61.0	62.1	62.0	62.1
Pomeroy	—	56.3	58.0	60.0	—	58.1	—	58.2	59.5	61.5	—	59.7
Walla Walla	—	61.0	60.0	61.7	—	60.9	—	62.5	61.0	62.3	—	61.9
Lind	—	56.0	—	59.5	—	57.8	—	57.0	—	60.0	—	58.5
Aberdeen†	—	57.2	61.2	60.0	—	59.5	—	57.7	62.0	61.5	—	60.4
Logan†	—	60.5	60.5	62.0	60.0	60.8	—	61.5	59.0	62.5	60.5	60.9
Bozeman†	—	60.2	62.0	64.5	—	62.2	—	60.8	62.5	65.8	—	63.0
Prosser†	—	—	—	61.7	—	61.7	—	—	—	62.7	—	62.7
Hesperus†	—	—	—	61.0	—	61.0	—	—	—	60.0	—	60.0
Mesa†	—	—	—	—	60.5	60.5	—	—	—	—	63.0	63.0
Average	—	57.7	60.1	60.6	59.1	59.5	—	59.1	60.8	61.3	60.4	60.5
Times superior	—	0	1	2	0	3*	—	9	7	11	5	32*

*Times superior for individual station years.
†Grown under irrigation.

The average number of heads per row of the Baart×Onas cross at seven stations in 1936 and nine stations in 1937 was 455 for the awnleted composite and 460 for the awned composite. This difference is not significant. While the number of heads per row was not recorded in 1938 and 1939 (except at Pullman, Wash., in 1939), there were no observable differences between the awnleted and awned composites in stand, date of heading, plant height, etc. At Pullman in 1939 there was an average of 408 heads per row in the awnleted composite and 421 heads in the awned composite. This difference is not significant, although the difference in yield was 4.0 bushels per acre.

TABLE 3.—*Yield of composites of awnleted and awned segregates.*

Station where grown	Yield in bushels per acre											
	Awnleted composite						Awned composite					
	1935	1936	1937	1938	1939	Av.	1935	1936	1937	1938	1939	Av.
Triplet × Oro												
Pullman	85.8	53.8	78.2	75.7	67.0	72.1	87.8	51.0	80.7	72.2	64.0	71.1
Walla Walla	43.7	50.8	—	40.2	51.7	46.6	42.2	52.7	—	40.0	51.3	46.6
Pomeroy	52.7	36.5	33.0	26.5	31.0	35.9	61.7	36.5	30.7	27.2	36.0	38.4
Lind	25.2	—	—	17.9	13.2	18.8	23.3	—	—	17.6	13.1	18.0
Pendleton	34.9	32.1	34.1	46.8	37.2	37.0	33.4	34.4	34.2	44.2	37.7	36.8
Moro	9.1	15.5	26.3	22.2	24.4	19.5	7.9	17.3	23.3	21.4	26.2	19.2
Union	54.3	53.0	—	56.2	55.3	54.7	48.9	51.3	—	52.4	48.2	50.2
Moscow	24.6	—	61.1	57.5	52.3	48.9	38.3	—	56.3	57.5	58.0	52.5
Tetonia	25.3	18.5	30.3	37.1	23.6	27.0	22.7	18.5	25.3	33.2	23.7	24.7
Sandpoint	35.7	—	51.4	54.2	44.3	46.4	32.5	—	59.1	54.8	41.3	46.9
Rockland	22.9	8.2	—	—	—	15.6	22.8	7.9	—	—	—	15.4
Clarkston	—	—	21.0	37.7	—	29.4	—	—	25.0	37.7	—	31.4
Average	37.7	33.6	41.9	42.9	40.0	39.4	38.3	33.7	41.8	41.7	40.0	39.2
Times superior	8	4	4	8	5	29*	3	4	4	3	5	19*
Baart × Onas												
Pendleton	—	37.2	37.4	40.9	35.1	37.7	—	42.1	38.7	44.8	42.0	41.9
Moro	—	13.1	19.9	23.8	17.2	18.5	—	15.6	25.5	25.2	18.4	21.2
Union	—	49.2	57.0	52.3	—	52.8	—	50.6	53.7	52.8	—	52.4
Moscow	—	38.8	54.4	36.4	—	43.2	—	38.8	50.5	37.8	—	42.4
Tetonia	—	20.3	34.7	32.4	—	29.1	—	18.0	34.8	33.6	—	28.8
Sandpoint	—	31.9	31.5	—	—	31.7	—	33.8	27.0	—	—	30.4
Pullman	—	57.3	59.8	45.7	40.5	50.8	—	61.3	61.8	50.5	44.5	54.5
Pomeroy	—	27.3	28.0	27.3	—	27.5	—	28.0	28.5	29.7	—	28.7
Walla Walla	—	45.3	24.8	45.3	—	38.5	—	46.8	27.3	50.2	—	41.4
Lind	—	15.3	15.2	17.8	—	16.1	—	13.5	15.1	28.4	—	19.0
Davis	—	—	—	47.0	36.6	41.8	—	—	—	48.3	39.9	44.1
Aberdeen†	—	76.9	75.4	76.6	59.4	72.1	—	77.0	75.7	78.7	61.4	73.2
Logan†	—	72.7	44.2	59.8	69.0	61.4	—	69.2	52.3	76.6	78.5	69.2
Bozeman†	—	38.7	64.9	37.0	—	46.9	—	43.3	62.7	49.0	—	51.7
Prosser†	—	—	—	57.6	—	57.6	—	—	—	78.5	—	78.5
Hesperus†	—	56.1	74.5	45.9	—	58.8	—	47.0	69.8	63.0	—	59.9
Mesa†	—	—	—	—	59.0	59.0	—	—	—	—	50.4	50.4
Average	—	41.4	44.4	43.1	45.3	43.3	—	41.8	44.5	49.8	47.9	45.8
Times superior	—	4	6	0	1	11*	—	9	8	15	6	38*

*Times superior for individual station years.
†Grown under irrigation.

SUMMARY

Composited populations of homozygous awnless or awnleted and of awned plant segregates from two wheat crosses, Triplet×Oro and Baart×Onas, were grown in adjacent replicated nursery plots in 5 and 4 years, respectively, at several widely distributed western experi-

ment stations. The grain from the composite of awned plants was superior to that from the composite of awnless or awnleted plants in both kernel weight and test weight per bushel for each cross regardless of environment. Yields of the two composites from the winter wheat cross, Triplet×Oro, were not significantly different, but in the spring wheat cross, Baart×Onas, the awned composite yielded significantly more than the awnless or awnleted composite in 2 of the 4 years.

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THE EFFECT OF CALCIUM AND POTASSIUM FERTILIZERS ON THE SOLIDITY AND THE CALCIUM AND POTASSIUM CONTENT OF CANNED TOMATOES[1]

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FIRMNESS or solidity of tomatoes is of great importance in the quality of the canned product. A method developed at the New York State Agricultural Experiment Station for the treatment of tomatoes with soluble calcium salts (2)[3] during processing greatly increased the firmness of the canned product. Minute quantities of calcium taken up by the tissues by this method have definitely improved the solidity and increased the drained weight and firmness of the tomatoes.

The objects of the experiment reported here were two-fold. First, to find out if the application of calcium salts as an amendment to the soil in which tomatoes were grown would increase the uptake of calcium by the plant and result in an increase in the calcium content and firmness of the tomato fruit. It has been reported (1) that with an abundant supply of potassium there is some replacement of calcium by potassium in the plant. The second object was to test the effect of increasing amounts of potassium fertilizers on the firmness of the fruit and, particularly, to determine if increased potassium fertilizers would reduce the calcium content of the tomatoes.

EXPERIMENTAL METHODS

Nystate tomatoes were used throughout these experiments. They were grown on the Canning Crops Investigations Farm of the Experiment Station on 1/40th acre plats with all treatments replicated three times in randomized arrangement. The kind and amount of fertilizer applied to the various plats is shown in Table 1.

Only No. 1 tomatoes, graded at the farm, were delivered for canning. The fruit in the first set of samples, harvested on September 2, were ripe and fairly soft. At the time of the experiment this was attributed to the holding of the fruit in storage overnight prior to canning. Later tests showed, however, that holding tomatoes overnight in storage had little effect on the firmness of the canned product. The tomatoes from each lot were handled separately in a commercial cannery. They were washed, steamed, peeled, cored, and packed by hand in No. 2½ size cans[4] in the first series (September 2) and in No. 2 size cans in the second series (September 11 and 12). The weight of tomatoes put into each can was noted on the outside of the can to allow a precise calculation of the "drained weight" in relation to the "put in weight". No salt was added to the first lot, but 35-grain

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[3]Figures in parenthesis refer to "Literature Cited", p. 394.

[4]The authors are indebted to the Research Department of the American Can Company for assistance in the canning of the tomato samples, and to the Geneva Preserving Company for the use of their factory for canning the several lots of tomatoes.

salt tablets were added to the cans of the second series. The cans were filled with tomato juice from the respective lot of tomatoes and closed cold by a Canco 006 vacuum closing machine. The No. 2 and No. 2½ size cans were processed for 55 and 60 minutes, respectively, in boiling water.

The samples were opened for observation after two months' storage. The method described by the Bureau of Agricultural Economics, U. S. Dept. of Agriculture, was used to determine the drained weight. The drained tomato meat was subsequently analyzed for calcium and potassium, using the official methods. To avoid the very confusing effect of the unavoidable variation in the "put in weight", the amount of tomato solids which stayed on the screen was expressed as the percentage of the weight of tomatoes placed in the can.

EXPERIMENTAL RESULTS AND DISCUSSION

The results of the "drained weight" analyses are presented in Table 1. It appears from an examination of these data that the differences in the drained weight content of the samples did not exceed the variation usually observed in individual cans of tomatoes prepared from the same lot of fruit. The percentage of "drained weight" in all samples was between 63.2 and 77.0% of the "put in weight". Recent work at this Experiment Station (3) showed that the addition of small quantities (0.07%) of calcium chloride to the can or dipping the fruit into a 1% solution of calcium chloride solution for 1 minute is in all cases sufficient to increase the drained weight of the tomatoes to over 80% of the "put in weight". Nothing approaching such an effect could be observed in the present samples showing that neither the calcium nor the potassium used as a fertilizer had any significant influence on the firmness of the canned fruit.

In order to affect the firmness in a manner similar to the treatment of the tomato fruit before or during preservation, the calcium supplied as fertilizer would have to find its way into the fruit through the plant. The fact that the calcium content of tomatoes is only insignificantly, if at all, influenced by calcium supplied in the fertilizer is well demonstrated in Table 2. Although occasionally the calcium content of the tomatoes from some plats was slightly higher than that usually found in fruit grown under commercial conditions, this slightly increased calcium content could not be associated with any consistent increase in the drained weight in the canned samples.

Table 2 also shows that the tomatoes did not take up any significant amount of potassium from that provided in the fertilizers. Tomatoes were analyzed for potassium from a plat receiving the highest amount of potassium (600 pounds 5–20–20; No. 2 Tables 1 and 2), from a plat receiving no potassium (600 pounds 5–20–0; No. 1, Table 2), from a plat receiving a small amount of potassium (600 pounds 5–20–5; No. 3, Table 2), and from a plat receiving this same amount at planting time plus a late side dressing of an equal amount of nitrogen and potash. Since these extreme differences in amount of potash fertilizer used resulted in no significant differences in the percentage of potassium found in the tomatoes, it was not considered worthwhile to analyze the entire series of tomatoes for potassium.

TABLE 1.—*Fertilizers applied and results of determinations of "drained weight" in experimentally canned whole tomatoes.*

Plat No.	Treatment*	Average "drained weight" as percentage of "put in weight"†			Yield per acre, tons
		1st series	2nd series	Average of all samples	
1	600 lbs. 5–20–0 drilled	74.8	69.5	72.2	9.18
2	600 lbs. 5–20–20 drilled	71.8	75.4	73.6	11.09
3	600 lbs. 5–20–5 drilled	69.9	76.4	73.2	9.86
4	100 lbs. sulfur (300 mesh) broadcast + 250 lbs. Ammo Phos 11–48 drilled	72.8	64.3	68.6	8.87
5	200 lbs. sulfur (300 mesh) broadcast + 600 lbs. 5–20–5 drilled	69.2	63.2	66.2	8.96
6	20 lbs. borax, 150 lbs. $MnSO_4$ and 250 lbs. $MgSO_4$ broadcast + 600 lbs. 5–20–5 drilled	68.7	77.0	72.8	8.47
7	1000 lbs. $CaCl_2$ broadcast + 600 lbs. 5–20–0 drilled	72.7	65.8	69.2	7.31
8	20 lbs. borax, broadcast + 600 lbs. 5–20–5 drilled	71.7	71.8	71.8	10.06
9	250 lbs. Ammo Phos 11–48 drilled	72.7	65.6	69.1	9.02
10	600 lbs. 5–20–5 drilled + NK side dressing later. July 25	73.6	70.1	71.9	9.89
11	600 lbs. 5–20–0 drilled + 500 lbs. $CaCl_2$ late side dress	68.3	66.1	67.2	8.51
12	250 lbs. Ammo Phos 11–48 drilled + 500 lbs. calcium chloride broadcast	—	71.8	71.8	8.23
13	1200 lbs. gypsum broadcast + 600 lbs. 5–20–5 drilled	73.9	71.7	72.8	9.87

*Broadcast treatments applied May 20 and disced in. Drill treatments applied May 31 and not disturbed. Tomatoes transplanted June 1, 3 rows per plat; rows 5 feet apart; plants 3 feet in row. The superphosphate used contained about 50% $CaSO_4$. In order to obtain fertilizer free from calcium, the P_2O_5 in plats 4, 9 and 12 was supplied in the form of commercial ammonium phosphate (Ammo Ps 11–48 containing 11% N and 48% P_2O_5).

†Averages obtained from two or three samples.

TABLE 2.—*Results of chemical analyses of tomatoes, 1939.*

No. Plat	1st harvest canned		2nd harvest canned		
	Dry matter, %	Calcium, %	Dry matter, %	Calcium, %	Potassium (as K_2O), %
1	6.32	0.0057	5.78	0.0050	0.312
2	6.10	0.0059	5.61	0.0044	0.343
3	6.57	0.0067	6.31	0.0056	0.324
4	6.70	0.0066	6.23	0.0055	—*
5	6.68	0.0141	6.70	0.0044	—*
6	6.43	0.0164	6.57	0.0046	—*
7	6.50	0.0081	6.88	0.0046	—*
8	6.75	0.0065	6.80	0.0054	—*
9	6.23	0.0115	6.72	0.0059	—*
10	6.58	0.0066	7.47	0.0049	0.312
11	6.70	0.0078	6.50	0.0090	—*
12	—*	—*	7.01	0.0047	—*
13	6.82	0.0146	7.02	0.0053	—*

*Not analyzed.

The differences in the potassium content of the samples analyzed are well within the natural variation; but in view of the generally accepted antagonistic effect of calcium and potassium, it is doubtful whether potassium reaching the fruit could increase its firmness. It has been shown (1, 5) that more potassium will cause a lower uptake of calcium. It is not quite certain that the effect of the natural calcium content on firmness is similar to that of the calcium salts used in producing the "calcium effect" in processing. But if it is so, then any improvement caused by the potassium would have to be great enough also to counteract the lowered solidity caused by the diminished calcium content of the tissues.

The soil on which these tomatoes were grown is classified as Ontario silt loam. The pH of the soil is 7.3. There are many small fragments of limestone scattered through this soil. There is no evidence that calcium is a limiting factor in plant growth. The abundant supply of calcium may explain why the liberal application of calcium salts as soil amendments did not significantly affect the calcium content of the tomatoes (Table 2) grown on this soil. In order not to change the pH of the soil, two neutral salts of calcium ($CaCl_2$ and $CaSO_4$) were used in certain field treatments (Nos. 7, 11, 12, and 13) in this test. The calcium chloride is very readily water-soluble and on account of its deliquescent character very quickly dissolved in the soil. The gypsum, though less soluble, supplies calcium to the plant in a very readily available form.

All of the fertilizer treatments carrying superphosphate also contained gypsum. Therefore, only in treatments 4 and 9, in which the phosphorus was supplied in Ammo Phos, was there no calcium salt applied in the fertilizer treatment. In treatment 12 the same amount of Ammo Phos was used as in treatment 9, but in No. 12 an active calcium salt (500 pounds $CaCl_2$) was also added. It is interesting to note in Table 2 that the tomatoes from treatment 9, in which no calcium salt was used, showed a higher calcium content than the

tomatoes from treatment 12 in which 500 pounds per acre of $CaCl_2$ had been applied. Evidently the tomatoes were abundantly supplied with calcium in this soil.

In treatments 4 and 5, respectively, 100 pounds and 200 pounds of very finely ground sulfur were applied. This would have a slightly acidifying effect on the soil, particularly the heavier application and would have a tendency to make the potassium more available to the plants by delaying the rate of fixation of potash in the soil. This might result in a greater uptake of potassium by the plants and a corresponding replacement of calcium, but Table 2 shows that it did not affect the calcium content of the tomato fruits.

Previous experiments on this soil (4) had shown that a lack of available phosphorus was the principal fertilizer factor limiting yields of tomatoes, and that only when liberal amounts of phosphorus and nitrogen fertilizers were also applied would potash fertilizers increase the yield of tomatoes. For that reason nitrogen and phosphorus fertilizers were applied uniformly to all the treatments in this experiment.

Treatment No. 1 (600 pounds 5–20–0) compared with treatment No. 3 (600 pounds 5–20–5) and with treatment No. 2 (600 pounds of 5–20–20) furnishes a direct comparison of increasing amounts of potassium fertilizer with the nitrogen and phosphorus fertilizers identical in all of these treatments. It should be noted in Table 2 that the heaviest application of potash fertilizer, treatment 2 in which 120 pounds of K_2O were applied, did not significantly increase the potassium content nor decrease the calcium content of the ripe tomatoes as compared with treatment 1 in which no potash was used. Furthermore, treatment No. 10 (600 pounds of 5–20–5+sulfate of ammonia and muriate of potash as a side dressing to supply an additional 30 pounds of nitrogen and 30 pounds of K_2O per acre) also did not increase the potassium content of the tomatoes at all, nor did it have any appreciable effect on the calcium content of the fruit.

The yield records show that the soil did not supply potassium to the plant in sufficient amounts for maximum growth. The largest yield was obtained from treatment 2 which supplied the largest amount of potash (600 pounds 10–20–20). Increased yields were obtained from treatments 2, 3, 10, and 13, all of which supplied potash, as compared with treatments 1, 4, 7, 9, 11, and 12 in which no potash was used in the fertilizer application. These fertilizer treatments in which sufficient potash was supplied to increase the yields of the tomatoes did not, however, have an appreciable effect in increasing the potassium content nor decreasing the calcium content of the fruit.

CONCLUSIONS

On a soil in which calcium is naturally abundantly supplied and in which potassium is not adequately supplied for maximum crop yields, the addition of calcium salts or potassium salts as soil amendments in the amounts used in this experiment had no appreciable effect on the calcium or potassium content of tomatoes grown on the soil, nor on the firmness of the canned tomatoes as measured by the drained weight.

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AN IMPROVEMENT IN LYSIMETER DESIGN[1]

Ellis F. Wallihan[2]

THE use of lysimeters for the study of moisture and nutrient losses from soils by drainage has been widespread. In many cases information of a fundamental nature has been sought and a great deal of reliance placed on the results of lysimeter studies.

The most common lysimeter installation consists of a column of soil which has been isolated from the surrounding soil either by removal to a new location and placing in tanks or by building a wall around a portion of soil in place. In either case, the soil in the lysimeter is disconnected from the surrounding natural body of soil. This discontinuity results in abnormal soil moisture conditions within the lysimeter.

In spite of the fact that soil physicists have realized for some time that moisture conditions in lysimeters are often not comparable with those of the natural soil in place, there have been reported relatively few attempts to determine the nature and degree of the differences. Neal, Richards, and Russell[3] showed that the soil in the bottom of a lysimeter must be nearly saturated with water before drainage will occur. This fact may be explained as follows: In a soil containing an amount of moisture less than that required for saturation, the water is under capillary tension. The magnitude of this tension bears an inverse, though not linear, relation to the moisture content of the soil. Thus there is an energy gradient (due to capillary forces) tending to hold the water in the soil. In order to effect a removal of any portion of this water, it is necessary that an opposing energy gradient of greater magnitude than the existing one be applied. For example, in a lysimeter which is drained by gravity (a relatively constant energy gradient which tends to remove water from soil) it is apparent that water will drain from the soil only as long as the energy gradient due to capillary forces in the soil has a lower value than that of the opposing force, gravity.

The question arises, then, as to what is the capillary tension in the bottom of a soil column which just balances the force of gravity. In the work of Neal, Richards and Russell, referred to above, drainage failed to occur even when the capillary tension dropped to a value equivalent to a 1 cm of mercury column. In the work reported in the present paper drainage occurred when the capillary tension was about 2 cm of mercury. The exact value might be expected to vary somewhat with the lysimeter design and type of soil being used. In any case, it appears that a soil must be nearly saturated with water before drainage will be effected by the force of gravity only.

In contrast to the condition in lysimeters is that of a deep, well-drained soil in which the water table is at a considerable distance

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[3]Neal, O. R., Richards, L. A., and Russell, M. B. Observations on moisture conditions in lysimeters. Soil Sci. Soc. of Amer. Proc., 2:35–44. 1937.

below the surface. In this case the energy gradient due to gravity tending to move water downward through the soil mass is supplemented by the energy gradient resulting from the capillary tension in the soil below. Therefore, to an extent depending on the magnitude of this latter energy gradient, the downward movement of water from a given portion of soil will occur at higher capillary tensions in a natural body of soil than in the soil at the bottom of a lysimeter. The result is a higher moisture content in lysimeter soils than in similar soils in place.

As stated above, this discussion applies to well-drained soils. To the extent that drainage is impeded in soils by impervious layers, the moisture conditions in lysimeters may tend to approach the natural conditions.

On the basis of these considerations, it might be expected that conclusions drawn from lysimeter studies would not be applicable in all cases to field conditions. Some of the possible effects of the abnormal moisture conditions in lysimeters would be (1) more rapid evaporation of moisture from the soil surface resulting in reduced volume of percolate, (2) inhibition of nitrification and possibly the occurrence of nitrate reduction due to restricted aeration at the bottom of the soil column, and (3) attendant changes in chemical composition of the soil solution. Furthermore, since the volume of water retained in a given mass of soil might be greater in a lysimeter than in a natural soil, there would be in such cases more water available to plants grown on the soil.

The purpose of this paper is to report a study in which an attempt was made to correct the error, which heretofore has been inherent in lysimeter studies, by applying an artificial capillary tension in the bottom of the lysimeter. This was done by placing a tensiometer cup near the bottom of the soil mass and withdrawing soil water with controlled vacuum. It should be recognized that the work was exploratory in nature and there was not sufficient replication of conditions to permit exact quantitative conclusions. Rather it was proposed to determine (1) whether or not this method is a practical one for correcting the moisture conditions in lysimeters and (2) the general trend of results obtained as compared with those from the usual type of lysimeter.

MATERIALS AND METHODS

The four lysimeters used consisted of Pyrex glass cylinders[4] 12 inches in diameter and 30 inches deep with round bottoms. There was a 1-inch hole in the bottom of each cylinder. The open end of a tensiometer cup was inserted in this hole in the inverted position, thus leaving the porus wall of the cup inside the lysimeter to be in contact with the soil and the open end extending below the bottom of the cylinder. Thus the water could be allowed to drain through the tensiometer cup by gravity or be removed by vacuum applied to it. For the measurement of soil moisture conditions in the lysimeters, two tensiometers[5] were placed in each, one

[4]The author is indebted to the Department of Agronomy for the loan of these cylinders.

[5]For a discussion of tensiometers see Wallihan, E. F. Use of tensiometers for soil moisture measurement in ecological research. Ecology, 20:403–412. 1939.

about an inch from the bottom and the other 6 inches below the surface of the soil. A diagram of the complete assembly is shown in Fig. 1.

The soil used was a Dunkirk fine sandy loam obtained from a woodlot of mixed hardwoods near Ithaca, N. Y. Soils from the A_1 and C horizons were used separately, i.e., the bottom 21 inches of each lysimeter were filled with soil from the C horizon and a layer of A_1 horizon 6 inches thick placed on top of this. Each of the two lots of soil was thoroughly mixed and passed through a half-inch mesh screen prior to filling the lysimeters. Successive buckets full were placed in various lysimeters to create as great uniformity as possible. The soil was packed slightly by hand to prevent the occurrence of large channels through which water might flow. Each lysimeter was wrapped with building paper to prevent abnormal growth of algae next to the glass cylinder wall. To prevent serious disturbance of the soil when water was added, 15 grams of sugar maple leaves were spread over the surface of the soil in each lysimeter. Distilled water only was used, with equal amounts added to each lysimeter. Percolates were collected at irregular intervals.

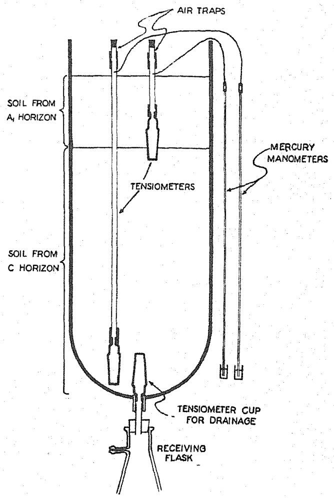

FIG. 1.—Diagram of the complete assembly of the lysimeters.

The plants grown during the second part of the experiment were oats. Twenty seeds were sown on each of two of the lysimeters and 19 plants resulted in each case.

Chemical tests were made as follows: Total nitrogen determinations were run on the harvested tops of the oat plants by the semi-micro Kjeldahl method, modified to include nitrate nitrogen. In the lysimeter percolates nitrate nitrogen was estimated by the phenol-disulphonic acid method and calcium by precipitation with oxalic acid and ammonia and titration with potassium permanganate. There was no replication of chemical determinations.

PROCEDURE

At the outset of the experiment 7 liters of water were added to each lysimeter and the excess removed from the bottom with a tension equivalent to 20 cm of mercury. After 12 days the moisture conditions in the four lysimeters were similar, as indicated by the tensiometer readings. At that time the vacuum was released

from lysimeters II and III, thus permitting them to drain freely, and a tension of approximately 10 cm of mercury was applied continuously thereafter to numbers I and IV. Irrigations were applied at irregular intervals. Over a period of two months the total water applied was 8.16 surface inches. During this period the tensiometers were read daily, with few exceptions. Early in the tests the deeper tensiometer in lysimeter II ceased functioning so no data are available for the moisture conditions at that position.

The data from this test make possible a comparison of the conventional type of lysimeter with that in which the drainage water is removed by suction, both in the fallow condition. It was desired to determine also their behavior when plants were grown in the soils. Oat seeds were therefore sown on lysimeters III and IV and allowed to grow until the plants were about 15 inches tall. Irrigation was discontinued early in their growth period to simulate a natural period of drought. The tops were harvested when the plants on lysimeter IV began to wilt. They were dried at a temperature of 70° C and weighed.

After the plants were harvested irrigation was resumed and continued until drainage occurred from all the lysimeters. The purpose of this treatment was to obtain final percolates from which could be determined the effect of the plants on the composition of the soil solution.

RESULTS

The tensiometer readings are shown graphically in Fig. 2. For lysimeters I, III, and IV the tensions reported represent conditions at the bottoms of the lysimeters. As mentioned above, comparable readings were not available for number II and the capillary tensions at the 6-inch depth in the soil are reported. However, these probably do not differ markedly from the values at the bottom of the soil column, as indicated by comparison of readings from the two tensiometers in lysimeter III which differed by only 1 to 2 cm of mercury column. Since lysimeters II and III were treated alike in the early part of the experiment, this comparison is feasible. The irrigations are charted at the bottom of Fig. 2 in surface inches. The duration of the experiment is divided into two phases, *viz.*, tests made while the soils were (1) all fallow, and (2) under crop in lysimeters III and IV.

In Fig. 3 are plotted the cumulative volume of percolate from each lysimeter and the cumulative volume of water added to the surface of each.

The volumes of the various portions of percolate are given also in Table 1. Incorporated in this table are the concentrations of nitrates and calcium in the percolates as well as the total amounts of these ions removed in each portion of percolate.

The data for the oat plants grown in lysimeters III and IV are given in Table 2.

DISCUSSION

In the tensiometer curves shown in Fig. 2, a comparison of lysimeters I and IV with II and III shows that the removal of drainage water by controlled suction (I and IV) was effective in preventing the waterlogged condition which occurred in the soils drained only by gravity (II and III). The volumes of percolate, given in Table 1,

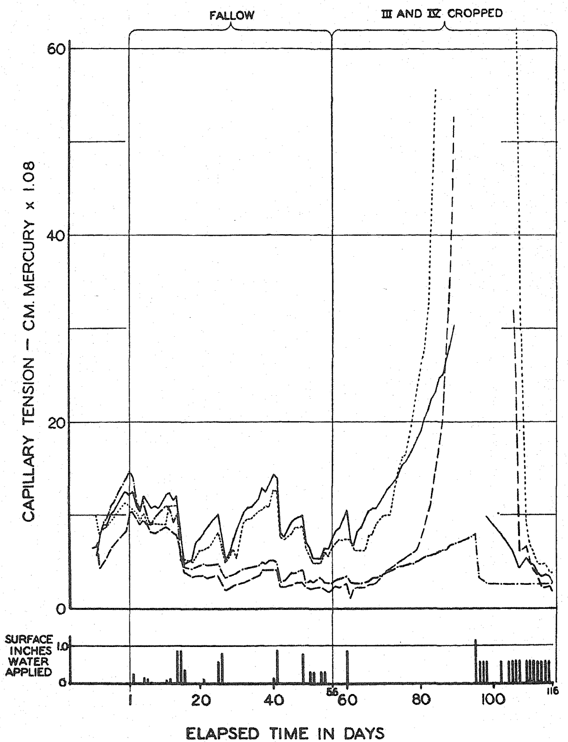

FIG. 2.—Capillary tension records from the lysimeters.

————————	Lysimeter I bottom
— · — · — · —	" II 6 inch depth
— — — — — —	" III bottom
· · · · · · · · · ·	" IV bottom

I and IV with tension; II and III without tension.

were about three times as great from I and IV as from II and III up to the time the oat seedlings became established. Comparison of I with II at the end of the experiment, since these had no plants grow-

TABLE 1.—*Volumes of lysimeter percolates, concentrations, and amounts of nitrates and calcium.*

Elapsed time in days	Volume of percolate, cc				Concentration of nitrates, P.P.M.				Concentration of calcium, P.P.M.				Total nitrates, mg				Total calcium, mg			
	I*	II*	III*	IV*	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
									All Lysimeters Fallow											
Initial wetting	895	730	368	187	30	33	33	36	24	24	23	26	27	24	12	7	21	17	8	5
	562	745	562	414	40	37	48	45	26	28	28	—	23	28	27	19	15	21	16	—
Total	1,457	1,475	930	601									50	52	39	26	36	38	24	5
5	54	—	—	60	56	—	—	56	36	—	—	37	3	—	—	3	2	—	—	2
9	130	—	—	155	69	—	—	77	31	—	—	35	9	—	—	12	4	—	—	5
14	50	—	—	60	74	—	—	87	34	—	—	40	4	—	—	5	2	—	—	2
16	357	—	—	430	118	—	—	105	49	—	—	42	42	—	—	45	17	—	—	18
17	438	—	—	530	125	—	—	111	48	—	—	44	55	—	—	59	21	—	—	23
18	290	—	—	200	100	—	—	100	50	—	—	44	29	—	—	20	14	—	—	9
19	360	—	—	95	125	—	—	100	49	—	—	47	45	—	—	10	18	—	—	4
20	245	—	—	285	100	—	—	95	47	—	—	45	25	—	—	27	12	—	—	13
25	565	—	—	525	136	—	—	124	48	—	—	49	77	—	—	65	27	—	—	26
26	165	—	—	240	140	—	—	145	50	—	—	51	23	—	—	35	8	—	—	12
28	550	140	200	680	157	122	106	122	52	45	47	52	86	17	21	97	29	6	9	35
33	760	133	83	955	174	134	131	167	56	46	49	54	132	18	11	160	43	6	4	52
46	325	280	115	370	245	170	170	245	65	52	55	65	80	48	20	91	21	15	6	24
53	—	465	330	—	—	188	222	—	—	54	58	—	—	87	73	—	—	25	19	—
56	910	315	240	920	286	231	240	333	76	55	62	72	260	73	58	306	69	17	15	66
Totals	5,199	1,333	968	5,505									870	243	183	935	287	69	53	291
Means†					167	182	189	170	55	52	55	53								

Oats Grown in Lysimeters III and IV

63	1,150	390	485	1,080	490	200	227	246	88	58	65	76	564	78	110	266	102	23	32	82
76	240	—	—	280	336	—	—	294	94	—	—	80	81	—	—	82	23	—	—	22
105	1,010	790	—	—	336	200	—	—	86	55	—	—	340	158	—	—	56	43	—	—
107	990	—	—	—	400	—	—	—	103	—	—	—	396	—	—	—	102	—	—	—
109	1,020	900	—	—	400	173	—	—	97	51	—	—	408	156	—	—	99	46	—	—
111	1,050	—	—	—	346	—	—	—	82	—	—	—	363	—	—	—	86	—	—	—
113	970	1,110	—	—	240	168	—	—	67	49	—	—	233	185	—	—	65	54	—	—
114	—	—	—	1,100	—	—	—	24	—	—	—	23	—	—	—	27	—	—	—	25
115	1,000	—	—	—	208	—	—	—	56	—	—	—	208	—	—	—	56	—	—	—
116	775	810	1,100	—	205	160	22	—	55	49	21	—	159	130	24	—	43	40	23	—
117	—	155	—	1,015	—	155	—	44	—	53	—	28	—	24	—	44	—	8	—	28
Totals	8,205	4,145	1,585	3,475									2,752	731	134	419	632	214	55	157
Means†					335	176	84	121	77	52	35	45								
Grand totals	14,861	6,953	3,483	9,581									3,672	1,026	356	1,380	955	321	132	453

*Lysimeters I and IV with tension; lysimeters II and III without tension.
†Means calculated from totals.

ing on them, shows the same relationship. This is due, in part, to the fact that all the lysimeters had approximately equal moisture contents at the beginning of the experiment, but during the remainder

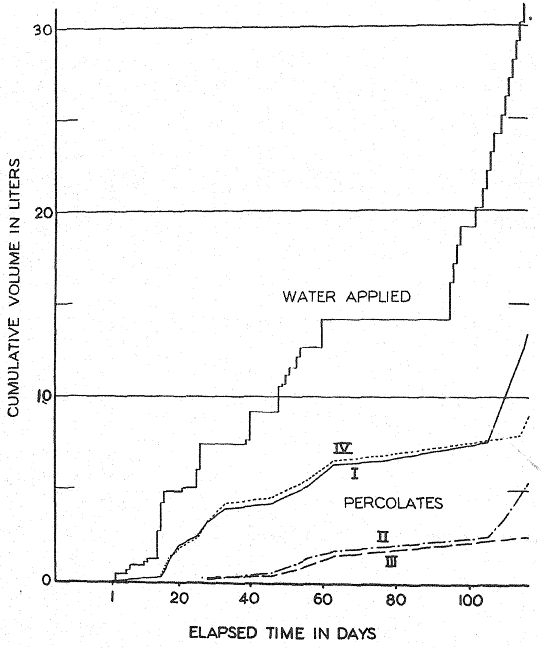

FIG. 3.—Cumulative volumes of water applied to and percolates from lysimeters.

———————————	Lysimeter I
—— · —— · —— · —— · ——	" II
—— —— —— —— —— ——	" III
· · · · · · · · · · · · · · · · · · ·	" IV

I and IV with tension; II and III without tension.

of the time a larger portion of the added water was retained by the soils in II and III than in I and IV. However, there is evidence that the rate of evaporation from lysimeters II and III was greater than

that from I and IV. Reference to Fig. 2 shows that on the fifty-third day of the experiment the capillary tension, and therefore the percentage of moisture, in each lysimeter was almost exactly the same as it was on the twenty-seventh day. Since equal amounts of water were added to each of the lysimeters, the volumes of percolates should have been equal if the rates of evaporation from the surface of the soil were the same. As a matter of fact, 1,635, 1,018, 728, and 2,005 cc of solution percolated from lysimeters I, II, III, and IV, respectively, during this period. One may conclude, therefore, that evaporation of water was most rapid from the lysimeters having higher moisture contents.

TABLE 2.—*Dry weights and nitrogen contents of tops of oat plants.*

Lysimeter No.	Dry weight of tops, grams	Total nitrogen	
		%	Grams
III (without tension)	21.0	2.78	0.584
IV (with tension)	11.8	3.02	0.536

Analyses of the percolates, reported also in Table 1, show that the concentrations of nitrate nitrogen and calcium in the soil solutions were greater in lysimeters I and IV than in those which were drained by gravity only. The differences in total amounts of these elements in the drainage waters were even greater. The low rate of nitrate accumulation in the poorly drained lysimeters can be explained, as suggested above, on the basis of the limited accessibility of oyxgen. The low calcium concentration is probably due largely, in turn, to the low anion concentration.

The relative dry weights of the oat plants produced on lysimeters III and IV appears to be important in spite of the fact that no replication of conditions was employed. Two factors apparently contributed to the greater amount of growth which occurred in lysimeter III. First, there was more water present in the soil than in number IV. Second, smaller quantities of soluble nutrients had been removed in the drainage water prior to sowing of the seed. It is interesting to note that if the nitrogen present in the tops of the oat plants is added to the amount removed in the percolate as nitrates, from the respective lysimeters, the totals are 0.6642 gram removed from lysimeter III and 0.6680 gram removed from lysimeter IV. Although the degree of significance of such a comparison is in doubt, it suggests that a certain amount of readily available nitrogen was present and that which was not removed in the drainage water was obtained by the plants, after aeration of the soil was improved through removal of water by the plants.

Two general conclusions might be drawn from this work. First, the data indicate that when the amount of moisture in a lysimeter is adjusted to correspond more closely with that in a natural soil, significant changes occur in the volume and composition of percolate. Second, the method which was used for correcting this error in lysimeter work shows considerable promise of being valuable for that

purpose. Further tests must be made, however, before extensive use is made of the method. It may be that in larger lysimeters the single tensiometer cup of the type used here will not be adequate for removing the water uniformly; but there appears to be no reason for not using more cups or a single unit with a larger porous area exposed to the soil.

The tension used in this work for aiding drainage was selected arbitrarily as being great enough to reduce the soil moisture to the point where diffusion of air would be greatly improved. Any tension from 0 to 60 cm of mercury column could be employed. It would seem feasible to have the tension controlled automatically so that it would be at all times the same as that which exists in a nearby (or even distant) natural field soil.

The degree to which results from larger lysimeters exposed to natural climatic conditions will differ from those reported in this paper will, of course, have to be determined by experiment. One might expect, however, that low atmospheric humidity would accentuate the difference in rate of evaporation. The relative humidity in the greenhouse varied during the course of this experiment from 30 to 50%, and was therefore considerably higher than that which commonly occurs under field conditions. On the other hand, the soil temperatures in these greenhouse lysimeters were undoubtedly higher and more uniform than would occur in lysimeters which are set in the ground. This factor might have affected moisture movements to some extent and also may tend to accentuate the differences in microbiological activity.

SUMMARY

Four small lysimeters were assembled in a greenhouse. Two were allowed to drain by gravity, according to the usual procedure. In the other two drainage was aided by the application, through tensiometer cups, of a tension equivalent to about 10 cm of mercury column.

As a result of this improved drainage, the rate of evaporation of water from the lysimeter was decreased, volume of percolate increased, content of nitrates and calcium in percolate increased, and growth of plants decreased.

Since this procedure rendered moisture conditions more nearly like those occurring in naturally well-drained soils, it was concluded that the abnormal moisture conditions in the ordinary type of lysimeter cause important errors in lysimeter studies. The method used here for correcting these conditions appears to offer possibilities for general use in lysimeter installations.

NOTE

A NEW METHOD FOR ALFALFA EMASCULATION[1]

THE suction method of emasculating alfalfa and sweetclover has been recognized as a more or less standard procedure. Results obtained at the Nebraska Experiment Station, however, have indicated that there is some doubt as to the thoroughness of such emasculation procedure. Tests comparing different methods were made in the greenhouse during the winter of 1939–40. When suction was used and no foreign pollen applied to the stigma, 14.11% of the flowers formed pods. If suction plus washing with a stream of water was used and no foreign pollen applied, 5.50% of the flowers formed pods.

The suction for use in this test was obtained from an electrically driven small suction pump which gives somewhat more suction than the intake manifold on a car, and great care was followed in making the emasculations.

In contrast with this method of emasculation, a new method using alcohol gives very few pods when the checks are allowed to develop without applying foreign pollen. The new method is performed essentially as follows: The standards are first clipped from the flowers in full bloom with sharp scissors and then the flowers are tripped, thus leaving the stigmatic column exposed for treatment. All the flowers to be emasculated on the raceme are treated in this manner. If the raceme has numerous flowers, it will usually be found more convenient to remove some of them to facilitate working. The whole raceme is then immersed in a small beaker containing 57% ethyl alcohol for 10 seconds. The raceme is then immediately transferred to a beaker containing water where it is rinsed for a few seconds, after which it is ready for pollination with the desired pollen. It apparently makes little difference if the pollen is applied immediately after emasculation or as much as an hour after emasculation, provided the adhering water is blown off the stigma before the pollen is applied. It is also well to blow the adhering anthers back from the stigmatic surface to allow contact for the foreign pollen. A convenient instrument to provide a stream of air is a dentist's syringe, or a bulb from an atomizer.

A number of tests have been conducted in the greenhouse, using different strengths of the alcohol and different time intervals. The results of these tests are given in Table 1, together with comparable tests of emasculation by suction, with and without the use of water.

These tests were run on comparable racemes of the same group of plants and thus the results between treatments can be directly compared. Too high a concentration of alcohol or too long a treatment injures the flower, resulting in fewer pods set. For example, 66.5% alcohol for 30 seconds practically kills the flower. A total of 14.7% of

[1]Contribution from the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and the Department of Agronomy, Nebraska Agricultural Experiment Station, cooperating. Published with the approval of the Director of the Nebraska Agricultural Experiment Station, Lincoln, Nebr., as Journal Series Paper No. 261.

the flowers formed pods when foreign pollen was applied after treating with 66.5% alcohol for 10 seconds, indicating some injury to the flower. This concentration gave good control, however, as only 0.78% of the flowers formed pods after emasculation. Controlled emasculation is not obtained by 66.5% alcohol for 1 or 5 seconds. On the other hand, 47.5% alcohol, at least for short periods of treatment, does not appear to be sufficiently strong to effect complete emasculation, since 3.10% of the flowers formed pods. For practical purposes 57% alcohol to be sufficiently strong and yet does not greatly injure the capacity to set seed, since 26.3% of the flowers set pods after pollinating with foreign pollen. This, however, is still somewhat lower than the untreated or suction-treated flowers which set 76.4% and 60% pods, respectively. The recommended time for the treatment with alcohol is 10 seconds, although some slight degree of latitude may be permissible with 57% alcohol.

TABLE 1.—*Percentages of alfalfa flowers forming pods after emasculation with different concentrations of alcohol compared to suction emasculation and to non-emasculated flowers, with and without foreign pollen added in each case.*

Emasculation method	Time immersed in alcohol, seconds	Number of flowers treated	Percentage of flowers forming pods	
			No pollen added	Foreign pollen added
47.5% ethyl alcohol*..........	10	198	3.10	41.4
57.0% ethyl alcohol...........	10	219	0.89	26.3
57.0% ethyl alcohol...........	10	50	—	32.0†
66.5% ethyl alcohol...........	1	98	5.10	—
66.5% ethyl alcohol...........	5	130	3.10	32.3
66.5% ethyl alcohol...........	10	256	0.78	14.7
Suction.....................	—	156	14.11	60.0
Suction+washing............	—	110	5.50	32.7
None.......................	—	348	36.10	76.4

*47.5%, 57%, and 66.5% alcohol can be conveniently obtained by using 50%, 60%, and 70% of 95% alcohol, respectively.
†One hour allowed to elapse between the time of emasculation and pollination; this is not, however, significantly higher than a comparable treatment pollinated immediately after emasculation. With this one exception all pollinations were made immediately after emasculation.

Pollen was collected from anthers after the anthers were treated with 57% alcohol for 10 seconds and tested for germination along with untreated pollen. Out of 33 tests only one of the treated sets showed any germination. In this one set, 2% of the pollen grains germinated and these had a very poor growth. On the other hand, the untreated pollen germinated from 10% to 80%, averaging 33%. Similar pollen, within the anthers, immersed in water for 15 seconds germinated an average of 15%.

Other experiments conducted at this station have shown that, if foreign pollen is applied to the stigma in addition to its own, it is the effective agent in fertilization from 70% to 98% of the time (unpublished data). Thus, if crosses are to be made which can be distinguished from selfs in the F_1, or, if it is not important that 100%

crossing is obtained, such crosses might be made without previous emasculation.

On the other hand, where care must be taken to produce known hybrids, it would seem that the emasculation by suction technic is not sufficiently accurate. The alcohol technic gives much better control. The use of alcohol for emasculation in alfalfa appears to be practical on either a small or a large scale and is much faster, simpler, and more efficient than the suction method.—H. M. TYSDAL and J. RUSSELL GARL, *Division of Forage Crops and Diseases, U. S. Dept. of Agriculture.*

BOOK REVIEWS

GROWING PLANTS IN NUTRIENT SOLUTIONS

By Wayne I. Turner and Victor M. Henry. xiii+154 pages, illus. New York: John Wiley & Sons, Inc. 1939. $3.

THIS book covers in a thoroughly practical manner the important considerations in growing plants in nutrient solutions, with special reference to commercial greenhouse culture. It comes from the hands of practical men who have been successful greenhouse operators and therefore emphasizes certain practical features, which are not present in all books available on this subject. It tells how to build the benches, how to convert old arrangements to the new method, how to plan the greenhouse, how to compute formulas, how to diagnose difficulties, what equipment to get and where to secure it. It is well illustrated with photographs from successful commercial set-ups and with outline drawings indicating types of equipment and methods of procedure. As a practical handbook it is one of the best along the newer lines of growing plants in nutrient solutions. (H. B. T.)

THE METEOROLOGICAL GLOSSARY

Issued by the Meteorological Office of the British Air Ministry. New York: Chem. Pub. Co. Ed. 3 (first American edition). 251 pages, illus. 1940. $3.

THIS book is a condensed manual of meteorology arranged alphabetically. While all the terms and concepts are explained tersely, there is much additional matter including tables, equations, constants, etc., which are of use to meteorologists and other scientists studying weather phenomena. In numerous instances three or four pages are devoted to information under a single term.

The work is very complete, including terms and concepts of physics, thermodynamics, statistics, chemistry, and geology which are used in the study of meteorology. The illustrations consist of graphs, weather maps, and classification of cloud formations. A section is devoted to the equivalent of English terms in Danish, Dutch, French, German, Italian, Norwegian, Portuguese, Spanish, and Swedish.

The text is well written, the presswork and binding well done, and the book should be welcomed by all who have occasion to refer to weather conditions and especially by agricultural scientists who study weather in relation to crops and pests. (F. Z. H.)

AGRONOMIC AFFAIRS

REPORT ON BIOLOGICAL ABSTRACTS TO THE UNION OF AMERICAN BIOLOGICAL SOCIETIES

THE steady conservative development of BIOLOGICAL ABSTRACTS continues. The Board of Trustees and editorial management are committed to a policy of prompt publication of authoritative and scholarly abstract issues and indexes, and every possible effort is being made to achieve both completeness of coverage and promptness in reporting the current literature of biology.

During 1939, 18,108 research papers were abstracted in BIOLOGICAL ABSTRACTS, an increase of 11% over the number of abstracts published the previous year. Coverage is still incomplete, but is being extended rapidly. By the end of 1939 arrangements were in effect for the regular, prompt abstracting of 1,150 of the world's most important biological periodicals, comprising, with scarcely an exception, the important English, French, and German serials in each department of biology.

Further expansion of coverage is necessarily dependent upon increased income. We can publish no more than we can pay for. Both as a safeguard against curtailment of foreign subscriptions and to finance desired improvements, increased subscriptions are necessary.

Every possible effort is being made to improve the quality of the service of BIOLOGICAL ABSTRACTS in every branch. Consultations with members of the Board of Trustees, members of the committees appointed by the various national societies, the Section Editors, and interested biologists generally, are almost constantly in progress and suggestions for improved coverage of the research literature are steadily being put into operation. In this connection we acknowledge with deep appreciation the services of Dr. E. V. Cowdry, retiring President, Dr. A. J. Carlson, the newly-elected President, and Dr. George W. Hunter, III, Secretary, of the Union, in providing effective contact between the BIOLOGICAL ABSTRACTS' organization and the national biological societies.—JOHN E. FLYNN, *Editor-in-Chief*, BIOLOGICAL ABSTRACTS.

SPECIAL SUMMER COURSES AT TEXAS A. & M. COLLEGE OF INTEREST TO AGRONOMISTS

THE DEPARTMENT OF AGRONOMY of the Agricultural and Mechanical College of Texas announces four special short courses this summer which will be of interest to agronomists. Each course will carry three hours credit and will be open to advanced undergraduate and graduate students.

FOREST SOILS—June 10 to July 20—taught by Dr. Robert F. Chandler, Jr., Pack Assistant Professor of Forest Soils, Cornell University. This is an advanced study of soils as they relate to forested areas. The course will also consider the climatic, physiographic, and biotic relationships of the typical southern pine forests, and the tension zone where the humid forest areas meet the semi-arid tall grass prairie of the Southwest.

RANGE MANAGEMENT AND ECOLOGY—June 10 to June 29—by Dr. W. G. McGinnies, Chief of Range Research Southwestern Forest and Range Experiment Station, Tuscon, Arizona. This course deals with range problems in the area west of the one hundredth meridian. The productive and carrying capacity of range land types of native vegetation, the possibilities of re-vegetation, principles of management and restoration, and a review of research work in the field will be studied.

PASTURES AND FUNDAMENTALS OF GRASS AND PASTURE IMPROVEMENT—July 22 to August 10—by Dr. F. D. Keim, Chairman, Department of Agronomy, University of Nebraska. The pasture problems of the Great Plains and the eastern half of the United States will be studied together with a review of pasture work throughout the world. The botany, the genetics, and improvement of pasture plants, and the principles of pasture research, ecology, and management will be studied exhaustively.

SOIL CLASSIFICATION AND MAPPING—August 12 to August 31—by Mr. E. A. Norton, Chief, Physical Surveys Division, Soil Conservation Service, Washington, D. C. In addition to a review of soil genesis, classification, and associations, emphasis will be placed on classes of land according to use capability, together with all types of surveys and field studies useful in the determination of a soil's character and use capability. The relations of large scale operations in this field will be considered from the standpoint of general agronomic import.

The above courses are designed primarily for professional workers. Those interested should write to Dr. Ide P. Trotter, Head, Department of Agronomy, Agricultural and Mechanical College of Texas, College Station, Texas, for further literature or information.

DOCTOR A. J. PIETERS AND PROFESSOR O. W. DYNES

THE AMERICAN SOCIETY OF AGRONOMY has lost two notable members of its group by death in the persons of Doctor A. J. Pieters of the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and Professor O. W. Dynes, Head of the Department of Agronomy, University of Tennessee.

Doctor Pieters died April 25 in his 74th year, and at the time of his death was in charge of the Lespedeza investigations being carried on by the Department. He had been associated with the U. S. Dept. of Agriculture since 1895 and had long been an active member of the American Society of Agronomy.

Professor Dynes died on May 6 at the age of 59. Professor Dynes became Head of the Department of Agronomy at the University of Tennessee in 1928 and Associate in Agronomy at the Experiment Station in 1936. He was a specialist in corn breeding and was an active member of the American Society of Agronomy and the Soil Science Society of America.

NEWS ITEMS

THE SOIL SCIENCE SOCIETY of Florida held a symposium on the afternoon of April 2, immediately preceding the meetings of the State

Horticultural Society at Tampa, in which the possibility of using soil reaction values expressed as pH as a basis for a liming program was discussed in detail. The state-wide interest in the problem was indicated by an attendance of over two hundred members and visitors.

GAYLORD M. VOLK, formerly Associate Soil Scientist in charge of the Soil Conservation Service Laboratory of Region 8, Albuquerque, New Mexico, has assumed the duties of Soil Chemist in charge of Soil Fertility Investigations at the Florida Experiment Station, Gainesville, Fla.

OWEN E. GALL, Research Assistant in Soil Chemistry at the Florida Agricultural Experiment Station, was recently appointed Junior Soil Scientist in the Soil Conservation Service.

THE IMPERIAL BUREAU OF PLANT BREEDING AND GENETICS, School of Agriculture, Cambridge, England, has published a bibliography on cold resistance in plants (price 1/6) and a pamphlet entitled "Field Trials: Their Lay-out and Statistical Analysis" by John Wishart (price 2/6).

DR. R. B. MUSGRAVE, who completed the requirements for the Ph.D. degree at the University of Illinois this year, has been appointed Assistant Professor of Agronomy at Cornell University. Dr. Musgrave will give special attention to problems in field crop ecology.

PRESIDENT F. J. ALWAY designated the following persons to act as delegates from the American Society of Agronomy to the Eighth American Scientific Congress in Washington, D. C., May 10 to 18: Dr. Oswald Schreiner and Dr. Richard Bradfield on the Section of Physical and Chemical Sciences and Dr. G. G. Pohlman, Dr. M. A. McCall, and Dr. C. E. Kellogg on the Section of Agriculture and Conservation.

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CALCIUM-POTASSIUM-PHOSPHORUS RELATION AS A POSSIBLE FACTOR IN ECOLOGICAL ARRAY OF PLANTS[1]

WM. A. ALBRECHT[2]

PLANT distribution and growth depend mainly on climatic factors. The soil in which plants grow is a resultant also of climatic forces. Consequently, we may well raise the question whether the degree of soil development or extent of nutrient depletion resulting from varying intensities of the climatic forces may not serve as an index to the ecological array of plant species. With the soil development and the plant distribution both determined by the same climate, then the nature of the soil and the distribution of the plants should agree. Which of the characteristics of the soil might control such an agreement, is a question that may well challenge speculative consideration.

Nitrogen, calcium, phosphorus, and potassium represent, in general, the major portion of soil fertility, or plant nutrient supply. Since the ultimate source of nitrogen is the atmosphere, then the plant nutrients of soil origin which are more commonly limiting plant growth, at least of legumes, can be considered to consist of calcium, potassium, and phosphorus. Further, since the variations in these three elements also dominate in the degree of soil development, may we not then look to the possibility that these same variations which reflect the effects of climate on the soil might also determine the ecological array? Some evidence and suggestions in support of such a possibility will be given consideration.

COMPOSITION OF VEGETATION REFLECTS INFLUENCE OF THE NUTRIENT DOMINANT IN THE SOIL

It is commonly agreed that potassium functions within the plant in carbohydrate production. In general, more potassium is required as more carbohydrate is produced. Potato tubers of almost pure starch, or carbohydrate composition, contain significant amounts of potassium. Sugar beets, sugar cane, sorghums, and other saccharine

[1]Contribution from the Department of Soils, Missouri Agricultural Experiment Station, Columbia, Mo., Journal Series No. 635. Also presented before the Crops Section at the annual meeting of the Society in New Orleans, La., November 22, 193[illegible]. Received for publication February 16, 1940.

[2]Professor of Soils.

crops make a decided demand on the soil for potassium. Perhaps we should discriminate whether this demand is for excessive amounts per acre annually along with similarly large amounts for other nutrients, or whether potassium is required in possibly no excessive total amounts but mainly in large amounts in comparison to other nutrients. Potassium or lye leachings from the ash of wood are known from the ancient arts. Forest soils, in general, are considered as low in phosphorus and badly leached of calcium. Though not absolutely rich in potassium, they may be relatively so.

The functions of phosphorus are commonly associated with reproduction, cell multiplication, growth, or protoplasmic activities, all of which are centered about a proteinaceous composition. Protein is characterized roughly as though it were a carbohydrate into which phosphorus and nitrogen have been combined. Phosphorus and nitrogen are thus associated with proteins while potassium dominates in carbohydrates.

Since calcium is a component of neither of the two preceding different composition groups that serve as constituents for the major portion of all plants, it might seem but fanciful imagination to give it importance as an ecological factor operating through protein production. Recent studies (4)[3] have given it an important role in nitrogen fixation by legumes. We may also well raise the question whether we understand fully its role in nitrogen metabolism of non legumes when we see their increased protein content by calcium treatment explained so casually as originating in the increased nitrogen supply from improved soil nitrification by liming as a soil treatment.

Studies (9) of the composition of grasses with increased protein brought about by liming suggest for calcium a much less indirect role in bringing about this improved activity in the production of protein. Thus, calcium may be significant in the formation of this type of nitrogenous compounds because it is connected with the process of bringing into the protein its characteristic nitrogen and possibly phosphorus. Calcium may thus be a controlling factor in ecology, and its wide fluctuation either as total supply in a soil or as saturating part of the adsorption complex may give it a larger role than is readily appreciated. Thus, if calcium functions strongly in nitrogen fixation and the consequent protein production, if phosphorus is likewise instrumental in augmenting this process, and if potassium is associated in the main with carbohydrate production, might we not expect that such soil conditions as allow one or the other of these elements to dominate in the nutrient supply will give dominance to one or the other of these corresponding functions in the flora?

CALCIUM-POTASSIUM-PHOSPHORUS AS VARIABLES WITH THE PHOSPHORUS LOW OR ALMOST A CONSTANT

Three variables present difficulties of determination by means of limited numbers of equations in experimental problems. Hence, since phosphorus is usually so low in most soils as to be considered almost the common regularly limiting factor, we may roughly reduce the

[3]Figures in parenthesis refer to "Literature Cited", p. 418.

variables in this case to calcium and potassium. If we may consider that phosphorus is a constant in nature when it is so low in quantity, so low in chemical mobility, and roughly at such a low base level above which the other two vary so much more widely, then the equations will include but two variables, calcium and potassium, for the problem in question here. If phosphorus is constant, then the calcium-potassium relations become the controlling factors in the ecological array and will not be so difficult of study. These two, under such an assumption, will be given the main attention in this discussion.

WHEN ARRANGED IN ORDER OF DECREASING PROTEIN CONTENT, PLANTS HAVE DECREASING NUTRIENT MINERAL CONTENTS

Studies (7) of the nitrogen contents, particularly of crops and vegetable plants, have made possible an array with different plants following in the order of decreasing protein or nitrogen contents. The legumes stand at the head of the list. Beginning with alfalfa, for example, followed by red clover, sweet clover, and others, including garden legumes, these crops can be arranged according to decreasing protein contents and lowering feeding or nutritional values commonly accepted in farm and household practice. As one goes down the scale to some of the legumes grown in the southern states, and of less nutrient value, there is still lower protein content, or lower total protein production per acre, and correspondingly lower total mineral content, particularly of calcium. Thus, there is less mineral per acre taken from the soil. The crops yield less protein per acre as their mineral supply decreases. With minerals coming only from the soil, its contribution of these may thus control the protein yield by the crop.

In arranging this order of decreasing protein production per acre by the legumes, there is no great gap in going from the lower legumes to those nonlegumes of higher feeding value. This higher value is also connected with the greater nitrogen content or total nitrogen in the crop. Hays from wheat, barley, rye, oats, bluegrass, timothy, redtop, and meadow fescue arrange themselves in this order of decreasing protein composition and reflect their commonly accepted hay values in the same order.

This arrangement with reference to higher proteinaceous nature of the different species, both legume and nonlegume, might serve as a pattern against which there can be matched also the calcium-potassium requirements as concentrations within the crop or the needs per acre. Studies (7) show the calcium decrease to go parallel with the nitrogen decrease, particularly in concentration within the plant. They reflect also different yields of total protein and nutrient minerals per acre in this general arrangement. When the potassium in the more commonly accepted field and vegetable crops is charted in this array according to decreasing calcium taken, or nitrogen delivered, by the crop, there is not the close agreement shown between calcium and nitrogen. Perhaps no great variation in the carbohydrate, or carbonaceous, part of the plant that amounts to a total of 50% need be expected even when there is a decided variation in protein of

which the total content scarcely ever exceeds 5%. Sampling for nitrogen variation over so narrow a range may not represent random sampling for the potassium associated with the carbohydrate. With these feed crops already selected according to animal choice for feed significance, the range in potassium may still not be wide enough to represent its possibilities for variation. When one considers woody plants, or takes woody tissue as an illustration, the dominance of potassium as compared to nitrogen and phosphorus is characteristic. Thus, we may regard potassium consumption as characteristic for the wood producers or for plant skeleton production, and calcium and phosphorus consumption as characteristic for the producers of protein. Perhaps it might be simpler to consider that all plants use some amounts of all nutrients but that with a low phosphorus level in all soils, the protein-producing plants are more common when calcium dominates in the soil supply, while with the decline or exhaustion of calcium the potassium dominates not necessarily by magnitude but by contrast. It is then that the more carbonaceous, or less proteinaceous, vegetation prevails.

SOIL DEVELOPMENT SUGGESTS DECREASING EXCHANGEABLE CALCIUM IN RELATION TO EXCHANGEABLE POTASSIUM

If this reasoning is sound, then the plant ecological array bids fair to be fitted into the complex picture of soil development according to climate. By accepting the colloidal clay particle as the nutrient-supplying nucleus of the soil, let us first consider it as neutral in reaction, and stocked liberally with the exchangeable cations of nutrient significance. Such a soil nucleus is characteristic of the chernozem soils produced in climatic areas where precipitation and evaporation are almost in equilibrium and temperatures are moderate. With increasing rainfall at such temperatures this nucleus exchanges the nutrient cations for the hydrogen ions of non-nutrient value. Consequently, the nucleus becomes acid. As the temperature becomes higher under liberal or excessive rainfall, this nucleus is broken down into less complex structures or compositions with less adsorptive or exchange capacity for nutrient cations. It likewise is less capable of holding exchangeable hydrogen ions or of showing significant degree of acidity. Thus, in the temperature zones, the complex nucleus of variable exchangeable calcium content is the characteristic of the soil. It usually has decreasing calcium with increasing hydrogen (and aluminium) as roughly the reciprocal under increasing degrees of leaching. In the warmer regions the simpler clay complex or nucleus carries little calcium and holds less of all nutrient contents.

ARTIFICIALLY DEVELOPED SOIL SHOWS NARROWING RATIO FOR EXCHANGEABLE CALCIUM-POTASSIUM

As an aid in visualizing the changes within the soil colloidal complex while a soil develops or passes to higher degrees of weathering and greater nutrient loss, some research in Holland by Prillwitz (8) may be helpful. The soil was weathered artificially through sulfur treatment and its microbiological oxidation. The change in the clay

complex is shown in Fig. 1, representing the exchangeable cation variation and the loss in some of its exchange capacity. According to this scheme, one of the distinct features is the substitution for the bases by the hydrogen and aluminium. Still more distinct is the fact that the relative amount of calcium is depleted much more rapidly than any other exchangeable nutrient on the complex. With the in-

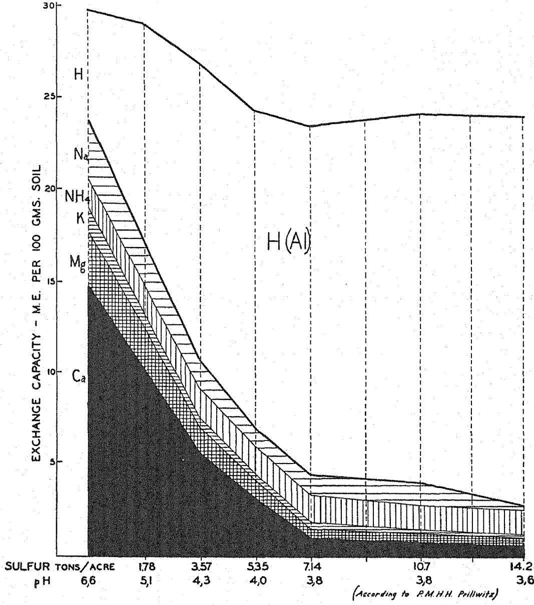

FIG. 1.—Varying relations of exchangeable cations, particularly Ca:K in a clay loam weathered to different degrees by sulfur additions.

creasing degree of soil development, the ratios of bases to each other shift, but of all the items, the calcium undergoes the greatest change. The ratio of this element to potassium shifts from approximately 11.0:1.0 at the pH figure of 6.6 to 4.0:1.0 at the pH figure of 3.8. If the anion of phosphorus is low at the outset and remains constantly so, then this shift in ratio of the calcium to potassium represents a decided change in the ratios of the nutrient offerings by a soil, even if the increasing clay content as a disturbing factor in offering of

totals is disregarded. The question may then well be raised whether such shifts in exchangeable cations may not be basic for an ecological shift from proteinaceous to non-proteinaceous plant dominance, or at least to less proteinaceous vegetation, as the soils are more highly developed and the clay complex simplified to a higher degree by the increasing forces of climate in the form of more rainfall or increasing temperature.

EXPERIMENTAL SHIFTS IN THE CALCIUM-POTASSIUM RATIO BRING SHIFT IN LEGUME FROM PROTEINACEOUS TO CARBONACEOUS PRODUCTION

As experimental help pointing toward the possible validity of the suggested array of dominant proteinaceous vegetation with high calcium to potassium ratio, let us note the behavior of soybeans as the calcium-potassium ratio was varied under control. When grown on a constant (5) but low phosphorus level, a constant but liberal calcium level, and with increasing potassium, all in the exchangeable or readily available form for the plant, this legume demonstrated a suggested shift from a proteinaceous producer to a carbonaceous producer. This is shown in Table 1. When the calcium relative to

TABLE 1.—*Decrease in nitrogen fixation and increase in crop weight of soybeans with widened calcium-potassium ratio.**

Exchangeable cations, M.E.			Crop weight, grams	Nitrogen		Magnesium		Calcium		Phosphorus		Potassium		$\frac{K\%}{Ca\%}$
Mg	Ca	K		%	Mgm	%	Mgm	%	Mgm	%	Mgm	%	Mgm	
5	10	0	14.207	2.86	407	0.36	52	0.74	105	0.25	39	1.01	150	1.36
5	10	5	14.592	2.56	372	0.36	54	0.32	46	0.18	26	1.90	285	5.93
5	10	10	17.807	2.19	390	0.30	55	0.27	48	0.14	25	2.15	384	7.96

*Seed content in mgm: N = 364, Mg = 16.7, Ca = 12.2, P = 39.4, K = 171.

potassium supply was high, this plant was a nitrogen fixer of moderate growth. When the increase in potassium was introduced so that the calcium was relatively low in relation to it, this plant grew larger, but its nitrogen-fixing activity dwindled. It consumed the offered nitrogen but diluted this with carbohydrate production. If it is true that this shift from protein to carbohydrate follows the shift in calcium-potassium ratio in the soil in the case of a single plant species, may it not be an epitome of the evolution of the ecological array of plants in accordance with the degree of development of our soils as measured by this shift in calcium-potassium ratio?

OBSERVATIONS ON SOIL DEVELOPMENT AND GENERAL VEGETATION AS POSSIBLE SUPPORT OF THE THEORY

It is commonly granted that dark soils are liberally stocked with calcium. It has been held by many that the calcium is the means of

preserving the organic matter. A different significance of the calcium seems more plausible in the light of studies of nitrogen fixation (1, 2, 6). Black soils naturally rich in calcium are usually correspondingly rich in all nutrient cations and are fit media for the mineral-consuming legumes. Calcium is significant for bringing nitrogen from the air to the soil. This added nitrogen serves to hold additional carbon as organic matter of nearly constant carbon-nitrogen ratio for each climatic location. Thus, soils high in exchangeable calcium produce more and retain more organic matter even though they also have their microbiological decomposition processes favored by these liberal stocks of cations (3). In going from these dark soils, according to the soil classification map, or to the rainfall map, to soils of lighter color with more rainfall at constant temperature, we go from prairies to forests and follow the general array of decreasing protein production and increasing carbonaceous, or wood, content in the vegetation. Increase in leaching means a soil complex whose potassium is still offered in exchangeable form in amounts to produce carbonaceous growth, and whose calcium and phosphorus levels maintain reproduction and cell multiplication sufficient to maintain this carbohydrate manufacture, but are not high enough to bring into this plant complex the extra nitrogen and phosphorus for plant types classified as distinctly proteinaceous.

In the extreme case of the forest tree we may visualize low calcium and phosphorus supply just sufficient to maintain a reasonable leaf area in metabolic activities of carbon assimilation and annual wood production. This leaf area may remain roughly constant with slight annual increase as it maintains itself at the top of the tree, with apical growth at the expense of translocation from the disappearing branches below. The pine in the sandy soils deficient in calcium but offering little potassium may illustrate the case with tall barren trunks tipped at great height by the green, photosynthetically active top. Students of the taxonomy of prairie vegetation have also reported the apparent increase in legume species in the prairie in going from east to west in Kansas or Nebraska, for example, or in going toward less leached soils or calcium carbonate horizons of less depth in the soil profile.

Since increasing temperature encourages soil development to the extent of colloidal clay breakdown, we must expect the well-developed or more highly simplified lateritic soil complex of lower exchange capacity to offer low amounts of calcium and to fit into the scheme as suggested. If such is true, the dominance of saccharine natured crops in the South would seem logical. The southern legume crops, when carefully studied, suggest that their properties fit them into soils of lower fertility when we know that they are more promiscuous in cross inoculation and in cross pollination, both of which are properties that aid in their struggle for maintenance against low soil fertility. Soils under high temperature and moisture have always been problem soils in fertility management. An application of the low calcium-potassium ratio theory and all that goes with it in the plant array may help us to understand some of the problems of agriculture in the South.

CALCIUM-POTASSIUM RATIO THEORY NEEDS FURTHER TESTING

Attention is not invited to the theory that the calcium-potassium ratio in soils of low phosphorus content controls, in a large measure, the ecological plant array because this theory has become a proved fact, but rather because, like many theories, whether ever proved or not, it may be helpful in making order out of chaotic thinking or of seemingly unrelated facts. If such an array is correct, can we not group our list of field crops for better adaptation to soils according to soil regions or to degree of soil development? Cannot soil treatment be used to improve the composition of the crops in the lower soil fertility phase of the natural ecological array? A fuller understanding of the relation of crops to soil conditions may reduce our search for crop plants from one of ramblings over the globe for promiscuous collectings and scatterings, to one of more carefully guided transfers from and to regions of common soil characters or even transfers to improved conditions for the crop.

It is for its possible help in clearer understanding of plants in relation to soil development and fertility that the calcium-potassium ratio theory suggested herewith is offered for your speculative consideration and for criticism.

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THE EFFECT OF LIMING ON THE ABSORPTION OF PHOSPHORUS AND NITROGEN BY WINTER LEGUMES[1]

FRANKLIN L. DAVIS AND CLAUD A. BREWER, JR.[2]

ALTHOUGH the increased yield of crops is usually accepted as a measure of the effects of applications of lime and fertilizers to soils, there is evidence that the yield alone does not fully evaluate the effects of such treatments. Numerous investigators (5)[3] have shown that the composition of plants varies with the composition of the soil on which they grow and that infertile soils produce crops low in mineral and protein content. Others (9) have shown that applications of fertilizers to poor soils usually result in an increased content in the plant of the elements supplied by the fertilizers. Such increases in the mineral content of feed and forage crops represent increased feeding value not measured by the yield.

Since calcium is the most abundant nutrient base found in normal soils, it is usually considered as being present in sufficient quantities for the normal nutrition of most crop plants, and liming the soil is looked upon as a practice to be used only when the soil becomes too acid to grow some desired crop. Chemical analyses of plants grown under field conditions prove that this is not always the case and show that crop yields may not be an accurate indication of the lime deficiency of soils. For example, Sewell and Latshaw (8) found that fertilizing with superphosphate did not increase the percentage of phosphorus in alfalfa, but that applying lime with the superphosphate did. Albrecht and Klemme (1) have reported field work in which applications of limestone and superphosphate almost doubled the calcium, phosphorus, and protein content of lespedeza forage over that obtained from superphosphate alone. These data show that the absorption of phosphorus and nitrogen was increased by liming and indicate that soils may be deficient in calcium without crop yields being seriously affected.

In a study of the factors affecting the inoculation and growth of winter legumes in Louisiana, data have been obtained on this subject. They show that liming increased the absorption of calcium, phosphorus, and nitrogen by winter legumes and that many Coastal Plains soils may be so deficient in calcium as to curtail seriously the normal absorption of phosphorus by crop plants even when it is supplied by fertilizer applications.

EXPERIMENTAL

Both Austrian winter peas (*Pisum arvense*) and common vetch (*Vicia sativa*) were planted in cooperation with farmers at various locations throughout the

[1]Contribution from the Department of Agronomy, Louisiana Agricultural Experiment Station, University, La. Paper presented at the Forty-first Annual Convention of the Association of Southern Agricultural Workers held in Birmingham, Ala., February 7, 8, and 9, 1940. The work reported was supported in part by a grant of funds made by The Urbana Laboratories, Urbana, Ill. Received for publication March 6, 1940.

[2]Associate Soil Technologist and Graduate Fellow, respectively.

[3]Figures in parenthesis refer to "Literature Cited", p. 424.

state. Each test included plantings of both crops on separate plots as follows: Plot 1, uninoculated, not fertilized; plot 2, inoculated, not fertilized; and plots 3 to 8, inoculated and fertilized with various fertilizer and lime treatments. Superphosphate containing 18% P_2O_5 was applied at the rate of 225 pounds per acre at the time of planting and 1,000 pounds per acre of lime were applied, either at the time of planting or a week or 10 days before.

Essential information concerning the location of the tests, the character of the soils, and the dates of planting and cutting are given in Table 1. Yield weights were obtained by weighing replicated cuttings from each treatment at the time of turning under the crop. Weighed samples of the green matter were taken at the same time for chemical analyses.

TABLE 1.—*Location of test, soil type, exchange capacity, exchangeable calcium, and dates of liming, planting, and taking yield weights.*

Soil No.	Location (parish)	Soil type	Date of liming, 1937	Date of planting, 1937	Date yield weights taken	Base exchange capacity, M.E. per 100 grams	Exchangeable calcium, M.E. per 100 grams
212	Natchitoches	Ruston sandy loam	Sept. 21	Sept. 30	Mar. 11	1.89	1.20
215	Ouachita	Orangeburg fine sandy loam	Sept. 20	Oct. 1	Mar. 28	1.75	1.03
216	Washington	Cahaba fine sandy loam	Oct. 11	Oct. 11	Mar. 23	4.00	1.40
217	St. Landry	Lintonia t. loam	Oct. 13	Oct. 13	Feb. 28	7.45	2.15

The results of the field work in detail and recommendations concerning the culture of the legumes are given elsewhere (3). Only those data bearing upon the effect of liming on the growth and composition of the legumes are considered here.

RESULTS

Satisfactory inoculation and growth of the peas and vetch were obtained at four locations in 1937–38. The average growth and percentage composition of the green matter in calcium, phosphorus, and nitrogen of these crops are given in Table 2. The average total quantities absorbed per acre are also shown.

The data in Table 2 show that liming increased the total growth and absorption of calcium by the legumes whether they were fertilized or not. Where no superphosphate was applied, liming resulted in a decrease of the average percentage content of phosphorus with only a small gain in the total quantity absorbed per acre. Where superphosphate was applied, liming produced an increase in the average percentage content of phosphorus with a resultant large increase in the total amount absorbed per acre. The absorption of nitrogen behaved somewhat similar to that of phosphorus.

The data are presented graphically in Fig. 1. The graphs aid in visualizing the relative importance of increased growth and change in

TABLE 2.—*The effect of liming on the growth and composition of winter legumes.*

Treatment	Average moisture content of green matter, %*	Average yield, tons green matter per acre*	Average composition of green matter, %*			Average quantity absorbed per acre, lbs.*		
			CaO	P_2O_5	N	CaO	P_2O_5	N
Not Fertilized: Lime Alone Compared to no Treatment								
Lime	82.1	3.79	0.26	0.08	0.53	19.1	6.5	41.7
No treatment	81.8	2.95	0.20	0.09	0.51	12.4	6.2	31.5
Increase from lime	—	0.84	0.06	−0.01	0.02	6.7	0.3	10.2
Percentage increase from lime	—	28.3	27.3	−12.2	4.5	54.0	5.7	32.4
Fertilized with Superphosphate: Lime and Superphosphate Compared to Superphosphate Alone								
Lime and superphosphate	82.9	6.29	0.28	0.11	0.62	35.0	14.8	81.2
Superphosphate alone	82.8	5.25	0.23	0.10	0.55	25.0	11.0	60.5
Increase from lime	—	1.04	0.05	0.01	0.07	10.0	3.8	20.7
Percentage increase from lime	—	19.8	20.4	14.4	12.4	39.8	35.2	34.3

*Average of eight crops grown in 1937–38: four each of Austrian winter peas and common vetch.

composition in increasing the total amounts of calcium, phosphorus, and nitrogen absorbed. The increase in the absorption of calcium produced by liming is the result of both (a) an increase in growth and (b) an increase in percentage composition. In the case of phosphorus where no fertilizer was applied, there was only a small increase in the total amount absorbed. This small net increase is due entirely to an increase in growth since the average percentage composition was actually decreased. This can be ascribed to the effect of the lime on the solubility of native soil phosphorus. The increase in the amount of nitrogen assimilated where no fertilizer was applied is likewise almost wholly due to the increase in total growth. Quite a different picture is presented where superphosphate was applied. The increased absorption of phosphorus and nitrogen is due to both an increase in growth and an increase in the percentage content of the elements. Apparently liming enabled the plants to utilize larger quantities of the phosphorus supplied by the fertilizer application. And a corresponding increase in the assimilation of nitrogen also followed.

RELATION OF CALCIUM SUPPLY TO AVAILABILITY OF PHOSPHORUS

If a deficiency of calcium in soils limits the normal uptake of phosphorus by plants, as these data indicate, then the calcium supply of soils should throw some light on the relationship between the results of rapid tests for soil phosphorus and crop yields. With this in mind, data previously published by the senior author and others (4) on the

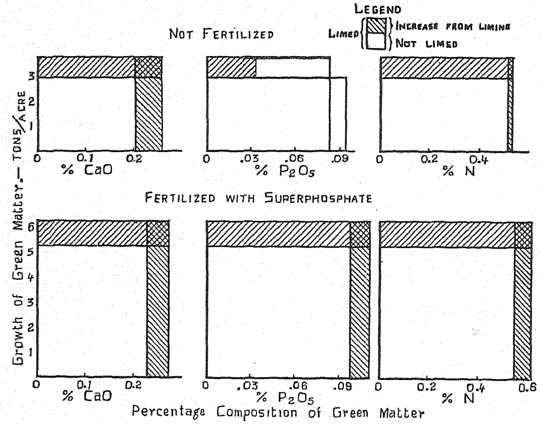

FIG. 1.—Effect of liming on the growth and composition of winter legumes.

correlation between crop yields and available phosphorus were reviewed. The graph showing the relationship between the amount of readily available phosphorus as determined by Truog's method and the yield of sorghum on 23 Greenville sandy loams is reproduced in Fig. 2. The values for the percentage calcium saturation of the soils were taken from Alabama Experiment Station Bulletin No. 244 (2) and are shown inserted on the graph.

It will be seen in Fig. 2 that all the soils on which the growth of sorghum (*Sorghum vulgare*) was considerably less than that expected from the quantities of available phosphorus present were low in exchangeable calcium. With but one exception, the degrees of calcium saturation were considerably less than the average (44.7%) for the entire group. In addition, those that produced more sorghum than was expected from the results of the available phosphorus test were considerably above the average in percentage calcium saturation. These data indicate that the calcium supply of soils is related to the utilization of soluble phosphorus by nonleguminous plants. This effect of calcium upon the absorption of phosphorus by plants warrants a careful examination in connection with the development of a rapid soil test for phosphorus suited to southern soils.

DISCUSSION

Liming soils fulfills two functions in connection with soil fertility and plant nutrition. First, it corrects soil acidity and produces a favor-

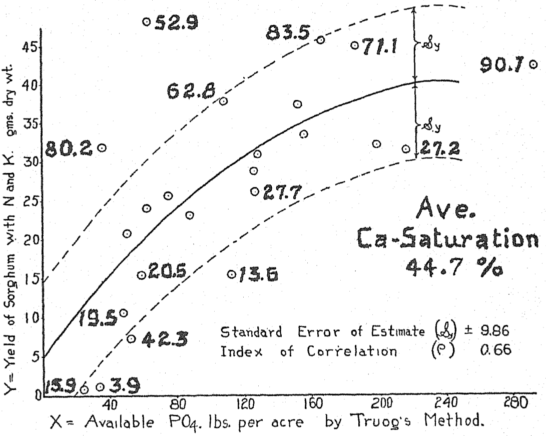

FIG. 2.—The percentage calcium saturation of soils as related to the relationship between the amount of readily available phosphorus and the yield of sorghum.

able reaction for the growth of plants. Second, it supplies calcium, or calcium and magnesium, needed for the nutrition of crops.

Soil reaction affects the solubility of most nutrient elements. At extremely acid reactions, toxic quantities of certain elements may be brought into solution. On the other hand, alkaline reactions often produce deficiencies by rendering essential elements insoluble. The maximum solubility of phosphorus, particularly, has been shown (7) to be dependent upon an optimum soil reaction.

The efficacy of liming in supplying nutrients has received much less attention than its effects upon soil reaction. It is known from work with nutrient solutions that a comparatively large quantity of calcium is essential to plant growth. Gedroiz (6) compared the growth of oats, and in some cases, of mustard and buckwheat, on a fertile soil to the growth obtained on quantities of the same soil with its exchange capacity saturated with each of the following bases: Hydrogen, ammonium, sodium, potassium, magnesium, calcium, strontium, cadmium, barium, manganese, ferrous iron, cobalt, nickel, copper, aluminum, and ferric iron. Only the calcium-saturated soil produced a crop growth equal to that of the original soil. Even when lime ($CaCO_3$) and nitrogen and phosphorus were added, a normal crop was obtained only from the hydrogen-saturated soil, on which the calcium replaced the hydrogen in the soil exchange complex. In 1921 True (10) found that the presence of a certain minimal quantity of

calcium ions was necessary for the normal absorption of ions of other elements. He also observed that the larger the variety of ions present the greater was the absorption of all electrolytes and the less marked the importance of the proportional concentration between ions.

The data obtained in this work are in line with these observations and serve to bring to our attention the stage of calcium depletion of many of our Coastal Plains soils. Because of the nature of the parent material the texture, and the warm, humid climate under which they have developed, Coastal Plains soils do not contain large quantities of nutrient elements even under virgin conditions. Their cultivation to cotton and tobacco for years has further depleted their supply of calcium. So long as these crops are grown, the need for building up the calcium supply does not become serious. However, with a reduction in the acreage of cotton and tobacco, these crops tend to be grown on the more fertile soils and the diverted acreage to consist mainly of the poorer lands. The use of these lands for pastures and the production of feed and forage is normal and should be encouraged. Such a utilization of soils low in calcium content will emphasize the problem of their fertility and make it increasingly important that their calcium supply be replenished by liming in order to produce larger yields of crops having a higher mineral and protein content.

SUMMARY

Both Austrian winter peas (*Pisum arvense*) and common vetch (*Vicia sativa*) were grown with various fertilizer treatments at a number of locations on upland soils in Louisiana. The composition of the soil and the growth and chemical analysis of the green matter produced were determined. The data show that liming soils low in calcium content enabled the crops to utilize larger quantities of the phosphorus supplied by applications of superphosphate. Lime alone produced an increase in percentage content of calcium only, while lime applied with superphosphate resulted in an increased content of calcium, phosphorus, and nitrogen.

Earlier data regarding the relationship between readily available soil phosphorus and crop yields are reviewed. These data further showed that those soils on which the yield of sorghum was unexplainably low in relation to the available phosphorus were also low in exchangeable calcium. It is thought that a low calcium content of soils will explain the lack of agreement between crop yields and rapid tests for phosphorus on many southern soils.

These facts are of the utmost importance to an expansion in the production of feed and forage crops on the upland soils of the southern states.

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GENETIC STUDIES WITH FOXTAIL MILLET, *SETARIA ITALICA* (L.) BEAUV.[1]

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VERY little is known about the genetics of foxtail millet. Rangaswami Ayyangar[3], in 1934, summarized the work that he and his co-workers in India had done. In this summary, he mentioned the inheritance of purple pigmentation of plant, grain color, anther color, bristles, lax earhead, spikelet type bristle, and albino seedlings. Li[4], also in 1934, found that the waxy endosperm of millet is inherited in a simple Mendelian fashion.

While the first two authors were carrying out millet breeding work in Honan University, Kaifeng, Honan, in 1932, many varieties of millet were collected. Attempts were made in crossing various types to study their genetic behavior. Some natural hybrids were also observed and collected. The subsequent generations were grown in the breeding garden of the National Wuhan University, Wuchang, Hupeh. Unfortunately, the soil was rather sticky and the weather was too rainy for a good millet crop. Thus, the populations of the segregating generations were relatively small and the plants were considerably deformed. Since 1938 the study has been continued at Chengtu, Szechuan, where the growing conditions for the millet are almost without an equal, even much better than those at Honan where the millet is grown most extensively. The results of these later studies are reported here.

SEED COAT COLOR

The mature grain of millet is enclosed by its lemma and palet which compose the seed coat. In the varieties of millet collected in Honan, there are five distinct color types for the seed coat, *viz.*, black, tawny buff, korra buff, red, and tawny red. While Rangaswami Ayyangar's description was closely followed, the classification was not always an easy one, the color varying tremendously with degrees of maturity. For instance, an unripe earhead with black seed coat is not black at all but tawny or korra buff in most of the seeds, although some seeds showed some black color. Again, there are many shades for the five color types mentioned, especially for the tawny buff and the red types. Nevertheless, when one is acquainted with the material, little difficulty will be encountered except with immature seed. It is fully realized that some of the data on color inheritance are rather meager, but they are presented here for what they may be worth.

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[1]Contribution from the Department of Farm Crops, Szechuan Provincial Agricultural Improvement Institute, Chengtu, Szechuan, China. Received for publication March 6, 1940.

[2]Head of the Department and Associate Agronomist, respectively.

[3]Rangaswami Ayyangar, G. N. Recent work on the genetics of millets in India. Madras Agr. Jour., 22:1–11. 1934.

[4]Li, H. W. Studies in the breeding methods for the foxtail millet. (In Chinese.) Col. Agr., Honan Univ. Bul. 2:1–21, 1934.

RED × KORRA BUFF

F_1 of the cross red × korra buff is tawny buff in color. The population in the F_2 is composed of four types, *viz.*, tawny buff, korra buff, red, and tawny red in a 9:3:3:1 ratio, as shown in Table 1.

TABLE 1.—*F_2 progenies of red × korra buff.*

P_1		F_1		F_2			
Color	Pedigree	Color	Pedigree	Tawny buff	Korra buff	Red	Tawny red
Red × korra buff	1–1	Tawny buff	111	20	7	8	1
Red × korra buff	1–2	Tawny buff	112	23	8	7	1
Red × korra buff	1–3	Tawny buff	113	16	9	8	1
Red × korra buff	1–5	Tawny buff	115	17	4	7	2
		Observed		76	28	30	5
		Calculated 9:3:3:1		78.12	26.04	26.04	8.68

P = .5

The probability of such a deviation from the expected value is 1.5. Similar deviation might therefore be expected once in two trials. Thus, the ratio of 9:3:3:1 denotes the action of two factors. Red might be assigned to a factor k and korra buff to r. Hence the four phenotypes will have the following factorial assignment:

Tawny buff KR
Korra buff Kr
Red kR
Tawny red kr

However, another cross which involves the same color types gives a quite different result. The F_1 seed instead of being tawny buff in color is distinctly black. In the F_2 there are five color types coming out instead of the four types mentioned above, as follows:

P_1	F_1	F_2				
Red × korra buff	Black	Black	Tawny buff	Sepia	Red	Tawny red
		36	4	11	3	1

It clearly indicates, therefore, that the hypothesis of two complementary factors is not sufficient to explain such behavior. In this case, either the korra buff or the red type must have two different genotypes to start with. In order to test our hypothesis, natural hybrids involving tawny red and black and the blacks from the F_2 were planted. The results are shown in Table 2.

Difficulties are likely to arise in differentiating between the blacks and sepias. The mature grain of both types show very little, if any, difference, but the immature grain is distinctly different. Immature grain of the blacks is either tawny buff or korra buff in color, never otherwise; while that of the sepias is either red or tawny red.

TABLE 2.—*F_2 and F_3 progenies of a cross of red×korra buff and F_2 progenies of natural hybrids between tawny red and black.*

Pedigree	Pedigree	Black	Tawny buff	Korra buff	Sepia	Red	Tawny red
F_1 1–4	F_2 114	36	4	0	11	3	1
	F_3 282	39	14	2	4	2	1
	284	11	3	0	7	4	7
	286	32	7	3	2	2	0
	326	1	1	1	2	0	2
	331	14	6	2	11	1	3
	335	4	5	0	4	5	3
	341	12	5	1	3	0	1
	344	17	7	1	1	1	0
	345	20	10	2	3	3	2
	348	5	4	0	3	1	1
	350	18	3	2	8	0	2
	363	32	13	12	9	4	7
	368	25	6	4	12	0	4
	369	10	5	7	5	1	3
	372	15	8	0	4	2	4
Natural hybrid	F_2 109	28	8	6	8	1	1
	110	21	8	5	5	1	7
Observed		340	117	48	92	31	49
Calculated 27:9:12:9:3:4		285.39	95.13	126.84	95.13	31.71	42.28

P = less than 0.01

Rangaswami Ayyangar stated in 1934 that six grain colors have been observed in *Setaria italica*, as follows: (a) Black, tawny buff, and korra buff, and (b) sepia, red, and tawny red. A factor K is present in group (a) and absent in group (b). In each of these two groups, the basic colors tawny red and korra buff with the addition of a factor I turn into red and tawny buff. This red and tawny buff with the addition of another factor B turn into sepia and black, respectively. Factor B has an individuality, but its presence is not visible except in association with I. Since we do not have the original paper in which this work is reported, it is impossible to tell how these conclusions were arrived at.

From our results, it is clear that we have two kinds of korra buff types. When crossed with red, F_1 seeds are tawny buff in one case and black in another. When sepia, red, and tawny red are considered separately (Table 2), they fit a 9:3:4 ratio closely, denoting the presence of two genotypes in tawny red. This phenomenon is verified again in the segregating generation of sepia, as will be seen later. Attempts have been made to cross tawny reds with tawny buff. Theoretically, one cross will obtain tawny buff F_1, but with another genotype, the F_1 will be black instead. Unfortunately, we failed to obtain such crosses. Should there be two genotypes for korra buffs and also two for tawny reds, the six types as shown in Table 2 should fit a 27:9:12:9:3:4 ratio so they are assigned to the following genetic factors:

Type	Color	Factor	Type	Color	Factor
1	Black	KRB	4	Sepia	kRB
2	Tawny buff	KRb	5	Red	kRb
3a	Korra buff	KrB	6a	Tawny red	krB
3b	Korra buff	Krb	6b	Tawny red	krb

The observed results do not fit the theoretical expectation well enough, however, for the P value is less than .01. Table 2 shows an overwhelming surplus of the blacks and a great deficiency of the korra buffs. The four other types fit the expectation almost perfectly. We can offer no explanation for this, except that possibly the number is not yet big enough. Further studies are in progress.

In order to check the hypothesis further, intercrosses were made between different color types. The results of which are given in Table 3.

TABLE 3.—*F_2 progenies of the cross tawny buff×black.*

P_1		F_1		F_2		
Pedigree	Color	Pedigree	Color	Pedigree	Black	Tawny buff
13×1	Tawny buff×black	154-1	Black	237	14	8
13×1	Tawny buff×black	154-2	Black	238	4	7
5×1	Tawny buff×black	171-1	Black	252	3	3
5×1	Tawny buff×black	171-2	Black	253	5	0
5×1	Tawny buff×black	171-5	Black	256	7	9
		Observed			33	27
		Calculated 3:1			45	15
		Dif.			12±2.26	

BLACK (TYPE 1)×TAWNY BUFF (TYPE 2)

The results of these crosses involving types 1 and 2 do not fit the calculated expectation well enough. The small number in the progenies might offer a reasonable explanation for such a deviation. The observed results do fit a 9:7 ratio perfectly, however, and should such be the case, tawny buff would not be type 2 but type 3b and the F_2 segregation would give rise to three color types instead of two. The pedigree 5 seeds used as one of the parents, however, were decidedly tawny buff (type 2). When crossed with korra buff (type 3b), a 3:1 ratio is obtained, as will be seen later. Thus, we might conclude that black (type 1) is dominant over tawny buff (type 2) with a single mendelian segregation.

BLACK (TYPE 1)×KORRA BUFF (TYPE 3B)

From Table 4, it can be seen that when type 1 is crossed with type 3b, three color types in a ratio of 9:3:4 are obtained. The fit is rather close to the theoretical result even with such small numbers. P is between .02 to .01. It is unfortunate that type 3a is not involved in any of these crosses.

TABLE 4.—*F_2 progenies of the cross korra buff and black as well as the F_3 progenies from the blacks in the F_2 which segregate for these types.*

P_1		F_1		F_2			
Pedigree	Color	Pedigree	Color	Pedigree	Black	Tawny buff	Korra buff
3×2	Korra buff×black	175–1	Black	263	13	5	3
3×2	Korra buff×black	175–2	Black	264	16	6	0
3×2	Korra buff×black	175–3	Black	265	5	2	0
2×3	Black×korra buff	179–1	Black	267	12	10	1
			F_3	285	19	2	3
				297	8	2	1
			F_4	597	14	3	5
				598	6	1	3
				Observed	93	31	19
				Calculated 9:3:4	80.37	27.79	35.72

P=.02 to .01

BLACK (TYPE 1)×RED (TYPE 5)

From Table 5, it is clear that a 9:3:3:1 ratio is obtained when crosses are made between blacks and reds, indicating a two factor difference

TABLE 5.—*F_2 progenies of the cross black×red and the F_3 progenies of the blacks in the F_2 segregating for these types.*

P_1		F_1		F_2				
Pedigree	Color	Pedigree	Color	Pedigree	Black	Tawny buff	Sepia	Red
2×9	Black×red	180–4	Black	272	11	5	0	1
2×9	Black×red	180–1	Black	273	6	1	0	0
10×1	Red×black	164–1	Black	242	4	9	13	2
			F_3	280	40	23	2	0
				289	20	8	0	4
				294	17	6	2	2
				300	13	5	5	1
				328	1	3	1	1
				333	8	3	3	1
				334	6	7	4	2
				337	8	9	4	0
				339	22	11	5	0
				342	29	5	9	6
				343	4	2	14	0
				362	22	10	4	0
				364	49	2	15	1
				365	33	10	12	3
				367	25	12	8	1
				370	19	8	5	0
				373	10	7	7	5
				375	10	7	3	0
				Observed	353	144	103	27
				Calculated 9:3:3:1	352.7	117.57	117.57	39.19

P equals .01

between these types. Relatively small populations in the progenies might lead to a wrong classification. For instance, pedigrees 280 and 339 may not belong to the right classes, thus explaining the poor fit, P equals .01. Such deviation as does occur from random sampling would only be once in a hundred trials. Here in this case, the excess class is the tawny buff and the deficient class is the red. We may conclude, however, that type 1 and type 5 are different in K and B and are similar in both having R factor.

TAWNY BUFF (TYPE 2) × KORRA BUFF (TYPE 3B)

There is only one factor difference between these two types (Table 6). This involves the factor B. The observed results fit the calculated expectation very well. Theoretically, when type 2 is crossed with type 3a, the F_1 seeds should be black, but such a cross was not made.

TABLE 6.—*F_2 progenies of the cross tawny buff and korra buff.*

P_1		F_1		F_2		
Pedigree	Color	Pedigree	Color	Pedigree	Tawny buff	Korra buff
24×25	Tawny buff×korra buff	133-2	Tawny buff	212	31	13
5×6	Tawny buff×korra buff	172-1	Tawny buff	257	15	3
5×6	Tawny buff×korra buff	172-2	Tawny buff	258	13	4
5×6	Tawny buff×korra buff	172-3	Tawny buff	259	14	3
5×6	Tawny buff×korra buff	172-4	Tawny buff	260	7	10
				Observed	80	33
				Calculated 3:1	84.75	28.25

Dif. $=4.75\pm3.10$

TAWNY BUFF (TYPE 2) × RED (TYPE 5)

Tawny buff is different from red in the K factor only. The observed results (Table 7) fit the expected calculation almost too good for such a small population.

TABLE 7.—*F_2 progenies of the cross tawny buff×red.*

P_1		F_1		F_2		
Pedigree	Color	Pedigree	Color	Pedigree	Tawny buff	Red
5×10	Tawny buff×red	169-1	Tawny buff	247	18	5
5×10	Tawny buff×red	169-2	Tawny buff	248	16	6
				Observed	34	11
				Calculated 3:1	33.75	11.25

Diff. $=0.25\pm1.96$

TAWNY BUFF (TYPE 2) × TAWNY RED (TYPE 6B)

The F_2 population of this cross (Table 8) is too small to have a good fit. Nevertheless, the data indicate a two factor difference between these types. According to the hypothesis, if type 2 is crossed with type 6a, the resulting F_1 seeds would be black in color, but unfortunately, attempts to make this cross were without success.

TABLE 8.—*F_2 progenies of the cross tawny buff × tawny red.*

P_1		F_1		F_2				
Pedigree	Color	Pedigree	Color	Pedigree	Tawny buff	Korra buff	Red	Tawny red
20×9	Tawny red × tawny buff	145–1	Tawny buff	222	4	7	1	3
			Calculated		9	3	3	1

KORRA BUFF (TYPE 3A OR 3B) × TAWNY RED (TYPE 6A OR 6B)

Most probably only the b type is involved in each of these cases.

The observed results (Table 9) fit the theoretical expectation perfectly. We may conclude, therefore, that there is only one factor difference (Kk) between these two types (3a and 6b). Crosses involving 3a and 6b or 3b and 6a were not met with in our experiment.

TABLE 9.—*F_2 progenies of the cross korra buff and tawny red.*

P		F		F		
Pedigree	Color	Pedigree	Color	Pedigree	Korra buff	Tawny red
20×25	Tawny red × korra buff	137–1	Korra buff	217	14	7
20×25	Tawny red × korra buff	137–2	Korra buff	219	21	8
20×25	Tawny red × korra buff	137–5	Korra buff	221	19	4
20×25	Tawny red × korra buff	137–3	Korra buff	223	6	1
				Observed	60	20
				Calculated 3:1	60	20
					Diff. = 0	

F_3 and F_4 progenies of sepia segregating for sepies, reds, and tawny reds are shown in Table 10.

From Table 10, it can be seen that the tawny reds have two genotypes. The observed results fit a 9:3:4 ratio very closely, with P between .95 and .90.

In order to test the hypothesis still further, the genotypes of F_2 of the various crosses were identified by observing their mode of segregation in the F_3 generation. In the cross, red and korra buff, the following genotypes should appear in the F_2:

Genotypes	Observed	Calculated 1:2:2:4:1:2:1:2:1
KKRR	3	4.4
KKRr	4	8.8
KkRR	14	8.8
KkRr	12	17.6
KKrr	5	4.4
Kkrr	10	8.8
kkRR	8	4.4
kkRr	10	8.8
kkrr	4	4.4
	70	70.4

P = .20

The frequency of the occurrence of the genotypes fits rather closely with the theoretical expectation. Such deviations as occur by chance would be once in five trials, P = .2.

TABLE 10.—*F_3 and F_4 progenies of sepia.*

Pedigree	Sepia	Red	Tawny red
	F_3		
354	24	10	15
355	15	7	4
356	8	3	4
357	19	6	10
358	21	5	10
359	16	6	4
	F_4		
609	21	1	2
610	12	1	1
611	8	1	7
Observed	144	40	57
Calculated 9:3:4	135.54	45.18	60.24

P = .95 to .90

In the cross korra buff (type 3a) and red (type 5), the blacks in the F_2 should have the following genotypes:

Genotypes	Observed	Calculated 1:2:2:2:4:4:4:8
KKRRBB	7	2.7
KKRRBb	10	5.4
KKRrBB	4	5.4
KkRRBB	8	5.4
KKRrBb	4	10.8
KkRrBB	7	10.8
KkRRBb	18	10.8
KkRrBb	15	21.6
	73	72.9

P = less than .01

TAWNY BUFF (TYPE 2)×TAWNY RED (TYPE 6B)

The F_2 population of this cross (Table 8) is too small to have a good fit. Nevertheless, the data indicate a two factor difference between these types. According to the hypothesis, if type 2 is crossed with type 6a, the resulting F_1 seeds would be black in color, but unfortunately, attempts to make this cross were without success.

TABLE 8.—*F_2 progenies of the cross tawny buff×tawny red.*

P_1		F_1		F_2				
Pedigree	Color	Pedigree	Color	Pedigree	Tawny buff	Korra buff	Red	Tawny red
20×9	Tawny red× tawny buff	145–1	Tawny buff	222	4	7	1	3
				Calculated	9	3	3	1

KORRA BUFF (TYPE 3A OR 3B)×TAWNY RED (TYPE 6A OR 6B)

Most probably only the b type is involved in each of these cases.

The observed results (Table 9) fit the theoretical expectation perfectly. We may conclude, therefore, that there is only one factor difference (Kk) between these two types (3a and 6b). Crosses involving 3a and 6b or 3b and 6a were not met with in our experiment.

TABLE 9.—*F_2 progenies of the cross korra buff and tawny red.*

P		F		F		
Pedigree	Color	Pedigree	Color	Pedigree	Korra buff	Tawny red
20×25	Tawny red×korra buff	137–1	Korra buff	217	14	7
20×25	Tawny red×korra buff	137–2	Korra buff	219	21	8
20×25	Tawny red×korra buff	137–5	Korra buff	221	19	4
20×25	Tawny red×korra buff	137–3	Korra buff	223	6	1
				Observed	60	20
				Calculated 3:1	60	20

Diff. = 0

F_3 and F_4 progenies of sepia segregating for sepies, reds, and tawny reds are shown in Table 10.

From Table 10, it can be seen that the tawny reds have two genotypes. The observed results fit a 9:3:4 ratio very closely, with P between .95 and .90.

In order to test the hypothesis still further, the genotypes of F_2 of the various crosses were identified by observing their mode of segregation in the F_3 generation. In the cross, red and korra buff, the following genotypes should appear in the F_2:

Genotypes	Observed	Calculated 1:2:2:4:1:2:1:2:1
KKRR	3	4.4
KKRr	4	8.8
KkRR	14	8.8
KkRr	12	17.6
KKrr	5	4.4
Kkrr	10	8.8
kkRR	8	4.4
kkRr	10	8.8
kkrr	4	4.4
	70	70.4

P = .20

The frequency of the occurrence of the genotypes fits rather closely with the theoretical expectation. Such deviations as occur by chance would be once in five trials, P = .2.

TABLE 10.—F_3 *and* F_4 *progenies of sepia.*

Pedigree	Sepia	Red	Tawny red
	F_3		
354	24	10	15
355	15	7	4
356	8	3	4
357	19	6	10
358	21	5	10
359	16	6	4
	F_4		
609	21	1	2
610	12	1	1
611	8	1	7
Observed	144	40	57
Calculated 9:3:4	135.54	45.18	60.24

P = .95 to .90

In the cross korra buff (type 3a) and red (type 5), the blacks in the F_2 should have the following genotypes:

Genotypes	Observed	Calculated 1:2:2:2:4:4:4:8
KKRRBB	7	2.7
KKRRBb	10	5.4
KKRrBB	4	5.4
KkRRBB	8	5.4
KKRrBb	4	10.8
KkRrBB	7	10.8
KkRRBb	18	10.8
KkRrBb	15	21.6
	73	72.9

P = less than .01

A poor fit is obtained between the observed and the calculated results. Such deviations by chance would occur less than once in a hundred trials. Since many of the populations in the F_3 families are too small, wrong classifications are likely to result, hence the poor fit.

When the sepias in the F_2 of the above cross were planted, the genotypes as presented below should be obtained:

Genotypes	Observed	Calculated 1:2:2:4
kkRRBB	6	2.33
kkRRBb	0	4.66
kkRrBB	4	4.66
kkRrBb	11	9.32
	21	20.97

P = between .02 and .01

The fit is not so good. The kkRRBb class is not obtained at all. Probably the explanation is that the number of families is rather small and the number in many of the families is too small for a correct classification.

From the data presented above it seems that the assumption of the interaction of three factors, K, R, and B, for the appearance of the six phenotypes in the seed coat color of foxtail millet is correct. It agrees closely with the hypothesis of Rangaswami Ayyangar and his co-workers. K and R are complementary factors. B is a supplementary factor, its presence being detected only when R is present. (R is the same as I of Rangaswami Ayyangar, the change being obvious from the data presented.) However, there are still some loopholes in the mode of inheritance for the blacks, tawny buffs, and korra buffs, that is, those with factor K. The data presented for their genetic behavior are too inconclusive. Further studies are necessary for their elucidation and are in progress.

ENDOSPERM CHARACTERS

WAXY VS. NON-WAXY

Waxy endosperm is frequently found in the cultivated foxtail millet. It is chiefly used in the making of pastry and wine. Like the glutinous rice, it is not grown extensively except for special purposes. Li[5] found that this character is inherited in a simple Mendelian fashion. It is recessive to its normal allele, the non-waxy type. The waxy character is easily identified by either macroscopic examination or by the simple iodine solution test as in the case with Zea, sorghum, pro-millet, etc. Further data on the inheritance of this character are presented in Table 11.

From Table 11, we can see that non-waxy and waxy endosperms are determined by a single gene, Wx and wx. The excess in the waxy class may be the result of faulty classification on account of the minuteness of the grains, or due to some other reason which is yet to be detected.

[5]Loc. cit.

TABLE 11.—*Segregation of non-waxy and waxy endosperm in the F_2 progenies.*

P_1		F_1		F_2	
Pedigree	Character	Pedigree	Character	Non-waxy	Waxy
21×10	wx.× wx.	135–1	Wx	263	107
21×10	wx.× wx.	135–2	Wx	239	91
20×25	wx.× wx.	137–1	Wx	263	111
20×25	wx.× wx.	137–2	Wx	218	67
20×25	wx.× wx.	137–3	Wx	120	53
20×25	wx.× wx.	137–4	Wx	132	45
20×25	wx.× wx.	137–5	Wx	149	51
20×25	wx.× wx.	137–6	Wx	127	61
13×20	Wx × wx	155–1	Wx	372	132
3×20	Wx × wx	173–1	Wx	165	74
2×11	Wx × wx	181–1	Wx	607	256
20× 9	wx × Wx	145–1	Wx	561	224
			Observed	3,216	1,272
			Calculated 3:1	3,336	1,112

Difference = 150±19.6

YELLOW VS. WHITE ENDOSPERM

Most of the cultivated foxtail millets have yellow-colored endosperm. Some varieties, however, have white endosperm. The results of a cross involving these color types is shown in Table 12.

TABLE 12.—*F_2 progeny of the cross of white and yellow endosperm.*

P_1		F_1		F_2	
Pedigree	Character	Pedigree	Character	White	Yellow
20×9	White×yellow	145–1	White	587	198
			Calculated 3:1	588.75	196.25

Diff. = 1.75±8.18

From the data presented in Table 12, we can conclude that endosperm color is determined by a single pair of allelomorphic genes, Ww. Waxy endosperm is also involved in the same cross. An independent segregation is obtained for these two factors, as shown in Table 13.

TABLE 13.—*F_2 progeny of a cross when Wx, wx, and Ww are involved.*

P_1		F_1		F_2			
Pedigree	Cross	Pedigree	Character	W Wx	W wx	w Wx	w wx
20×9	W wx×w Wx	145–1	W Wx	427	160	134	64
			Calculated 9:3:3:1	441.54	147.18	147.18	49.06

P = 0.1–0.05

EARHEAD CHARACTERS

PALMATIC VS. NORMAL EARHEAD

The earhead of the cultivated foxtail millet is characterized by having a main axis with many side branches (Fig. 1). The spikelets substending by bristles are borne on the lateral branches. There are many varieties of millet whose earhead is cylindrical in form, that is, the branches on the main axis are more or less equal in length throughout. However, there are several varieties in our collection with a palmatic type of head. The branches on the main axis gradually lengthen out from the tip of the axis downward. Sometimes the lower branches are about as long as the head itself, although of course, the number of branches of this extreme type is much less than in the normal type. As a result, the head resembles more or less a palm. In fact, the local name of such a variety is "monkey's hand."

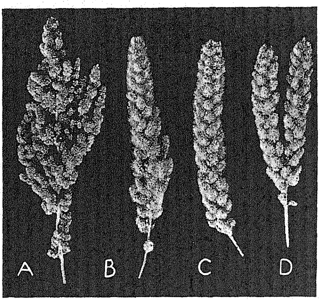

FIG. 1.—Variation in form of head of millet. A, palmatic form; B, palmatic form in a segregating generation, this type not apt to segregate again; C, normal head; D, double head.

When the palmatic type is crossed with the normal type, the F_1 is palmatic (Table 14), but this is rather intermediate in type. That is to say, the length of the branches is not as long as that of the typical palmatic type, and the number of branches is also intermediate between the normal and the palmatic type.

TABLE 14.—*F_2 progenies of a cross between palmatic and normal type of earhead.*

P_1		F_1		F_2		
Pedigree	Character	Pedigree	Character	Pedigree	Palmatic	Normal
24×34	Palmatic×normal	131–3	Palmatic	208	20	20
24×34	Palmatic×normal	131–5	Palmatic	210	23	13
24×25	Palmatic×normal	133–1	Palmatic	211	23	24
24×25	Palmatic×normal	133–2	Palmatic	212	18	16
			Observed		84	73
			Calculated	9:7	88.29	68.67

Diff. = 4.33±4.19

LIBRARY

The F_2 progenies were grown in the breeding garden of the National Wuhan University. As stated before, the soil and weather were not suitable for a normal crop of millet. As a result, the heads were rather deformed so that the classification was doubtful. In order to check upon this, F_3 progenies were grown. As the F_3 crop was grown at Chengtu, an ideal place for millet growing, classification was thus made easy, so the correction can be made according the mode of segregation. When the F_2 population is thus corrected, it fits a 9:7 ratio rather closely, even though the number is small. Hence, a duplicate factorial hypothesis is assumed. The palmatic type must have both P_1 and P_2 present. Either a single dominant dose or nil will result in normal type. In order to check upon this hypothesis further, the F_3 segregation will reveal the genotypes of the palmatic types in the F_2 as follows:

Genotypes	Observed	Calculated 1:2:2
$P_1P_1P_2P_2$	13	9.33
$P_1P_1P_2p_2$ / $P_1p_1P_2P_2$	15	37.32
$P_1p_1P_2p_2$	56	37.32

P = less than 0.01

As the number of the F_3 progenies is none too big, mostly around 50, the classification may be erroneous. Thus the fit is none too good, but it indicates strongly that our hypothesis is correct. The F_4 generation was grown in 1939 and the segregation checked rather closely with the above hypothesis.

NORMAL VS. DOUBLE EARHEAD

In several of the F_3 progenies of the cross involving palmatic and normal earhead, some double heads were noticed, but none had been found in the previous generation. The double heads have two normal earheads attached to a single shoot. Most of them are attached near the basal branch but sometimes they are connected at the middle of

TABLE 15.—*F_3 families segregate for double earhead.*

Pedigree	Normal	Double
439	63	1
446	56	1
441	75	1
450	70	1
454	85	2
458	61	2
Observed	410	8
Calculated 63:1	411.39	6.53
464	74	5
Calculated 15:1	73.95	4.93

the axis. Still others may branch out near the tip of the earhead, but, the latter type is infrequent (Fig. 1).

Since the double earheads apparently appear in a definite proportion of the population in a segregating progeny and since they seem to be inherited, the families in the F_3 which segregate for the normal and double earhead types are shown in Table 15.

If the double earhead type is inherited, a triple factor hypothesis should be assumed. It must be represented by the triple recessive and this must breed true in the following generation. Unfortunately, in planting the seeds from such a head, not a single double earhead was obtained. Thus, it is clear, that this is a chance variation and not inherited.

SUMMARY

Six color types for the seed coat of foxtail millet have the following factorial assignment:

Black	KRB
Tawny buff	KRb
Korra buff	KrB
	Krb
Sepia	kRB
Red	kRb
Tawny red	krB
	krb

Endosperm characters are all controlled by simple Mendelian factors, as follows:

Wx	non-waxy	wx	waxy
W	white	w	yellow

wx and w are inherited independently.

Earhead types may be palmatic or normal and are controlled by duplicate factors, P_1 and P_2, as follows:

9	P_1P_2	palmatic
	P_1p_2	
7	p_1P_2	normal
	p_1p_2	

Double earheads are not inherited.

A DIVISION OF THE ALFALFA CROSS-INOCULATION GROUP CORRELATING EFFICIENCY IN NITROGEN FIXATION WITH SOURCE OF *RHIZOBIUM MELILOTI*[1]

JOE C. BURTON AND LEWIS W. ERDMAN[2]

ASYMBIOTIC nitrogen-fixation relationship between leguminous plants and *Rhizobia* is known to be dependent upon the plant as well as the root nodule bacteria. The qualities or requisites for either have as yet been undefinable from a biochemical or physiological standpoint. Studies to date have dealt primarily with demonstrations of the phenomenon and the extent of its existence within the plant groups.

Previous studies have shown that a strain of bacteria efficient in nitrogen fixation on one leguminous plant within a cross-inoculation group is not necessarily efficient on other plants in the same group. They have also shown that there are all gradations in efficiency among strains of legume bacteria causing nodule formation on any one host plant. These studies demonstrate a group specificity with respect to the legume bacteria isolated from alfalfa (*Medicago sativa*) and sweet clover (*Melilotus* sp.), and their nitrogen fixation efficiency on burr clover (*Medicago hispida, arabica*) and fenugreek (*Trigonella Foenum-Graecum*), which belong to the same cross-inoculation group. When all, or the majority of all, strains of bacteria isolated from a particular leguminous plant fail to cause nitrogen fixation, although producing excellent nodulation on another plant within the same group, it reflects a change in the bacteria produced by the physiology or the chemistry of the plant itself. This phenomenon is demonstrated in these studies with *R. meliloti* isolated from alfalfa and sweet clover. It can not be demonstrated with strains of *R. meliloti* isolated from burr clover or fenugreek on the plants now included in the alfalfa cross-inoculation group.

HISTORICAL

A complete review of the literature up to 1932 showing strain differences in nitrogen-fixation efficiency and the part which the host plant plays in a symbiotic relationship is presented by Fred, Baldwin, and McCoy (5)[3] and also by Allen and Baldwin (1). Since then there have been a number of papers emphasizing the importance of the host plant in a bacteria-plant relationship. Bjalfve (2) found differential response among the vetches as to the number and position of the nodules and quantity of nitrogen fixed. Virtanen and Hausen (6) found that the most suitable strains of organism for one variety of peas was likewise the best for other varieties. In their studies, however, only two strains of the nodule organisms were used, hence the observation may be true for these two strains. It was proved not to be true when a larger number of strains were used by Erdman and Burton (4) in 1938. There was a marked differential response with respect to

[1]Contribution from Research Laboratory, The Nitragin Company, Inc., Milwaukee, Wis. Received for publication March 19, 1940.

[2]Assistant Bacteriologist and Chemist and Director of Research and Production, respectively.

[3]Figures in parenthesis refer to "Literature Cited," p. 450.

variety when eight strains of *R. leguminosarum* were tested for efficiency on four varieties of peas.

In 1937, Wilson, Burton and Bond (7) demonstrated an effect of species of host plant on nitrogen fixation in *Melilotus*. Because of the significance of the occurrence of this specificity of the host plant in the symbiotic nitrogen-fixation system from both a theoretical and practical point of view, these investigations were extended to the *Medicago*.

In 1939, Burton and Wilson (3) reported results obtained when three varieties of *Medicago* (Ladak, Hairy Peruvian, and Grimm) were tested for ability to fix nitrogen in association with nine strains of *R. meliloti*. The same nine strains of *Rhizobia* were also tested for nitrogen-fixation ability using five species of *Medicago* (*M. sativa*, *M. arabica*, *M. hispida*, *M. lupulina*, and *M. minima*). There was a definite host plant specificity among the five species of *Medicago*; however, the specificity among the three varieties of alfalfa was much less than that among the different species. In these studies only one strain of *R. meliloti* caused any appreciable nitrogen fixation on *M. hispida* or *M. arabica* which are two species of burr clover. This strain was isolated from alfalfa plants grown in a jar of sterile sand in the greenhouse and the source of bacteria was ripened burrs taken from burr clover plants and implanted with the sterile sand. This finding led to the present studies to find the cause of the high specificity demonstrated by burr clover.

METHODS

Essentially the same technic was used as described in previous publications (4, 7). Disinfected seeds were planted in jars containing sterilized sand and all the known necessary plant food elements except nitrogen. Triplicate jars were inoculated with each strain of the nodule organism at the time of planting. The plant cultures were grown in a thermostatically controlled greenhouse kept at 70° to 75° F and were supplied artificial light during extreme periods of cloudy weather. Bryan's modification of Crone's nutrient solution was added at 2-week intervals. Sterile distilled water was added as needed. The plants were grown for 60 to 90 days, the entire plant then being harvested, dried, and nitrogen analyses made, using the Kjehldahl apparatus.

EXPERIMENTAL

In a preliminary experiment during the fall of 1937, six strains of *R. meliloti* which were isolated from burr clover were used to inoculate two species of burr clover (*M. arabica* and *hispida*) growing in the same jars. The sources of all strains of the nodule bacteria used in these experiments are presented in Table 1. Growing conditions were extremely favorable and the nitrogen fixation by three strains was very high. The three other strains caused no significant increase in total nitrogen over the controls. The nitrogen-fixation data are presented graphically in Fig. 1.[4]

The nodulation produced by one of the highly effective strains is compared (Fig. 2) with that produced by one of the ineffective strains. The marked degree of specificity in this preliminary experiment led us to plan a second experiment using strains of *R. meliloti* isolated

[4]Each column in the graphs presented in this paper represents the average for three replicate plant cultures. Because of the length of the paper and the consistent agreement between replicates, the individual data are omitted.

from alfalfa, burr clover, and sweet clover to inoculate alfalfa, burr clover, sweet clover, and fenugreek, all of which belong to the same cross-inoculation group, in order to find some explanation for the marked specificity. Details of experiments 2 and 3 are as follows:

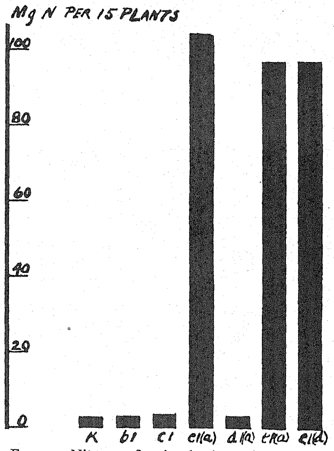

FIG. 1.—Nitrogen fixation by burr clover inoculated with six strains of *R. meliloti* from burr clover.

Experiment 2.—Twenty strains of *R. meliloti*, 8 of which were isolated from alfalfa, 7 from burr clover, and 5 from sweet clover, were used to inoculate alfalfa, sweet clover, burr clover, and fenugreek. The planting was made on Oct. 15 and the plants were harvested on Dec. 10. Triplicate jars were planted to each bacterial treatment. The growth conditions were quite satisfactory.

Experiment 3.—In this experiment 20 strains of *R. meliloti*, 6 isolated from alfalfa, 4 from sweet clover, 6 from burr clover, 3 from fenugreek, and 1 from bitter clover (*Melilotus indica*), were used to inoculate alfalfa, burr clover, and fenugreek. Planting was made on Feb. 10, 1939. The weather was cloudy during a large part of the time and mazda lamps were used to supplement the lighting. These unfavorable conditions, however, were not entirely undesirable because it gave opportunity to study the same phenomenon under different environmental conditions.

RESULTS

The data show two types of host plant specificity, *viz.*, (a) a specificity with respect to nitrogen fixation occurring when a strain of the legume bacteria invades the roots forming nodules on different species or varieties of legumes included in a common cross-inoculation group, and (b) a group host-plant specificity or non-symbiotic relationship with all *Rhizobia* isolated from other species included in the same bacteria-plant group. The former type has been discussed in previous publications and will not be discussed here except to illustrate the two types of response to strains of the legume bacteria.

The responses of alfalfa, sweet clover, and burr clover to *Rhizobia* isolated from these three legumes are given in Figs. 3, 4, and 5. In general, alfalfa responded well to alfalfa, sweet clover, and burr clover organisms, sweet clover to alfalfa, sweet clover, and burr clover organisms, and burr clover only to burr clover bacteria. The

TABLE 1.—*Sources of Rhizobium meliloti used for artificial inoculation of plants.*

Culture No.	Legume source	State	Year
3DOa1	*Medicago*	Wisconsin	1912
3DOa2	*Medicago sativa*	Wisconsin	1938
3DOa3	*Medicago sativa*	Wisconsin	1938
3DOa7	*Medicago sativa*	Minnesota	1932
3DOa10	*Medicago sativa*		1926
3DOa12	*Medicago sativa*		1928
3DOa14	*Medicago sativa*	Idaho	1928
3DOa15	*Medicago sativa*	Minnesota	1932
3DOa17	*Medicago sativa*	Minnesota	1932
3DOa26	*Medicago sativa*		1931
3DOc1	*Medicago arabica*	Mississippi	1937
3DOc1 (a)	*Medicago arabica*	Mississippi	1937
3DOc2	*Medicago arabica*	Mississippi	1937
3DOc3	*Medicago arabica*	South Carolina	1938
3DOc4	*Medicago arabica*	South Carolina	1938
3DOe1 (a)	*Medicago hispida*	Alabama	1937
3DOe1 (c)	*Medicago hispida*	Alabama	1937
3DOe1 (d)	*Medicago hispida*	Alabama	1937
3DOe2	*Medicago hispida*	North Carolina	1939
3DOd1 (a)	*Medicago hispida*		1928
3DOd2	*Medicago hispida*	California	1938
3DOb1	*Medicago lupulina*	Alabama	1936
3DOh3	*Melilotus alba*		1927
3DOh7	*Melilotus alba*	Michigan	1937
3DOh8 (a)	*Melilotus alba*	Alabama	1937
3DOh10	*Melilotus alba*		1937
3DOi3	*Melilotus officinalis*	Wisconsin	1938
3DOz1	*Melilotus indica*		1937
3EOf1	*Trigonella Foenum-Graecum*		1938
3EOf2	*Trigonella Foenum-Graecum*	Pennsylvania	1938
3EOf2 (b)	*Trigonella Foenum-Graecum*	Pennsylvania	1938

nodulation in every case was abundant; however, the alfalfa and sweet clover *Rhizobia* produced numerous, scattered nodules on burr clover. This is the type generally considered ineffective. That this was true is illustrated graphically by Figs. 6 and 7 which give the results of the nitrogen analyses on this experiment with alfalfa and sweet clover strains of *R. meliloti*.

Not one of the strains caused any significant nitrogen fixation on burr clover, although all strains except 3DOa26, which has consistently been parasitic on all the legumes in this group, caused considerable fixation on alfalfa and sweet clover.

The nitrogen fixation with burr clover strains shown in Fig. 8 illustrates only one type of specificity, e.g., specificity with an individual strain. 3DOe1 (d) and 3DOd2 are effective on all three host plants, while 3DOc1 is effective only for alfalfa.

In the same experiment (No. 2, Oct. 15 to Dec. 10, 1938) fenugreek was inoculated with seven of the same strains of *R. meliloti*. The results are given in Fig. 9.

Fenugreek demonstrates a similar non-symbiotic association with the *Rhizobia* from alfalfa and sweet clover to that of burr clover. Strains 3DOe1 (d) and 3DOc2 from burr clover fixed about 70 mg of nitrogen per 10 plants, while the other strains showed no significant

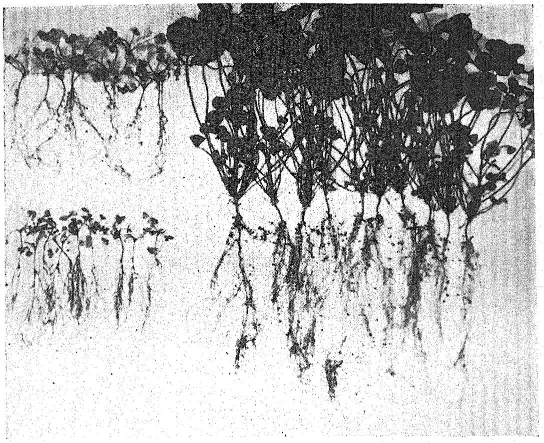

FIG. 2.—Nodulation produced by a highly effective and ineffective strain of *R. meliloti* on burr clover. *Right*, good strain; *upper left*, parasitic strain.

difference over the uninoculated control. Nodulation was abundant with all strains.

In experiment 3 (Feb. 10, to April 17, 1939) 20 strains of *R. meliloti*, including some recently isolated alfalfa and fenugreek organisms, were tested for nitrogen-fixation efficiency on alfalfa, burr clover, and fenugreek. Although the growing conditions were poor because of excess cloudy weather, the results confirmed the findings of the previous experiment. Fenugreek responded well to burr clover and fenugreek strains but failed to grow at all when inoculated with alfalfa and sweet clover isolations.

The fenugreek bacteria caused high nitrogen-fixation on burr clover as well as alfalfa and sweet clover, thus placing this legume in the same group with burr clover as to its specific bacterial requirements and response. The strains highly effective on fenugreek are usually highly effective on burr clover.

Nitrogen analyses of experiment 3 are represented graphically in Figs. 10 and 11. The same non-symbiotic relationship of the alfalfa and sweet clover bacteria with fenugreek was again confirmed in this study.

DISCUSSION

The results of the foregoing experiments only emphasize the complex relationship of the root nodule bacteria with leguminous plants

resulting in biological fixation of atmospheric nitrogen. The consistent failure of the legume bacteria isolated from alfalfa and sweet clover in causing nitrogen fixation on burr clover and fenugreek suggests two possibilities. Either the two latter plants are much more specific in their bacterial requirements than the former two, or the legume bacteria are actually changed through association with alfalfa and

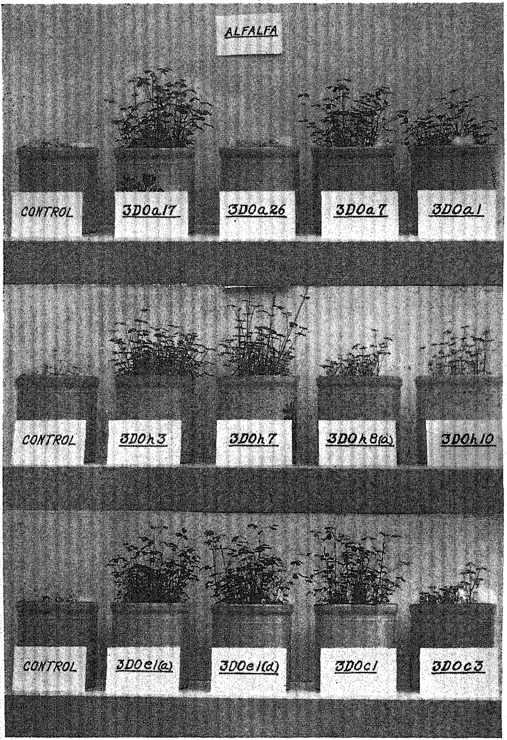

FIG. 3.—Alfalfa inoculated with *R. meliloti* from three sources. *Top*, alfalfa; *center*, sweet clover; *bottom*, burr clover.

sweet clover. If it is purely a question of host-plant specificity, then we must assume that the mechanism of nitrogen-fixation effected by alfalfa and sweet clover is different form that of burr clover and fenugreek inasmuch as nodulation occurred with all strains. However, since burr clover and fenugreek isolations also cause nitrogen-fixation on alfalfa and sweet clover as well as their mother host plant,

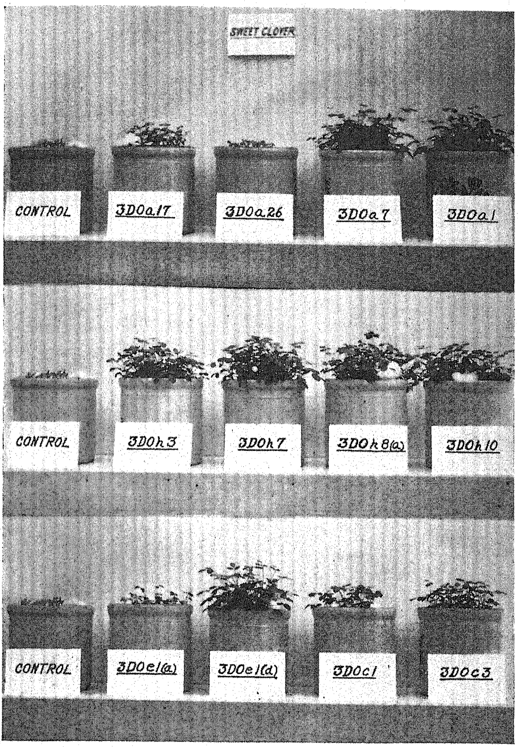

FIG. 4.—Sweet clover inoculated with *R. meliloti* from three sources. *Top*, alfalfa; *center*, sweet clover; *bottom*, burr clover.

it would seem that two mechanisms of fixation were not involved and that the bacteria had actually changed through association with alfalfa and sweet clover. In this case one would be led to believe that alfalfa and sweet clover plants, unlike burr clover and fenugreek, produce some component of fixation which results in the bacteria still being able to function efficiently on alfalfa and sweet clover, although

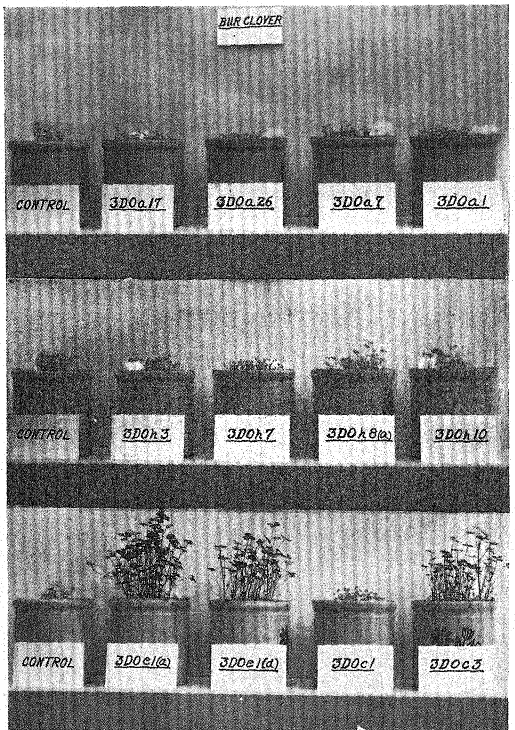

FIG. 5.—Burr clover inoculated with *R. meliloti* from three sources. *Top*, alfalfa; *center*, sweet clover; *bottom*, burr clover.

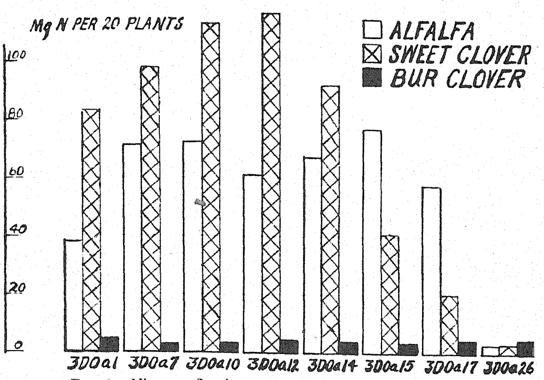

FIG. 6.—Nitrogen fixation produced by eight strains of *R. meliloti* isolated from alfalfa.

burr clover and fenugreek, being dependent upon the bacteria furnishing this component, are not able to fix nitrogen with strains of the nodule-organism which have been associated with alfalfa and sweet clover.

In these studies over a period of three years, 30 strains of *R. meliloti* have been tested for efficiency on the plants included within the alfalfa cross-inoculation group and without an exception the strains of bacteria isolated from alfalfa and sweet clover have failed to cause any nitrogen fixation on burr clover and fenugreek. We do not believe that strains of the bacteria which will be efficient nitrogen fixers on burr clover and fenugreek can not be isolated from alfalfa and sweet clover, but from these studies we have been led to believe that these bacteria upon repeated association with alfalfa or sweet

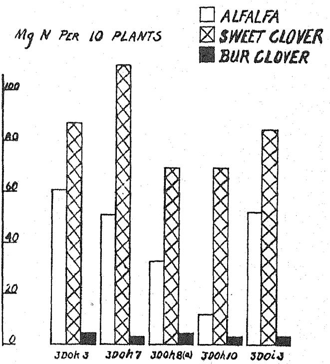

FIG. 7.—Nitrogen fixation produced by five strains of *R. meliloti* isolated from sweet clover.

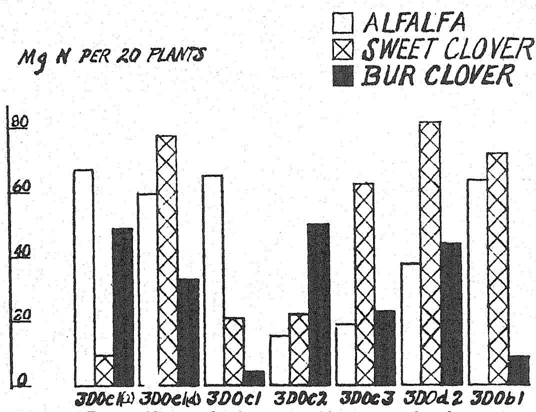

FIG. 8.—Nitrogen fixation produced by seven strains of *R. meliloti* isolated from burr clover.

clover soon lose their effectiveness on burr clover and fenugreek. Physiological studies have failed to reveal any noticeable differences between strains of the legume bacteria from different host plants. There are varying degrees of acidity in litmus milk, but this is true for the organisms from each host plant and there is no positive correlation between acidity and nitrogen fixation with any of the strains used on any of the host plants.

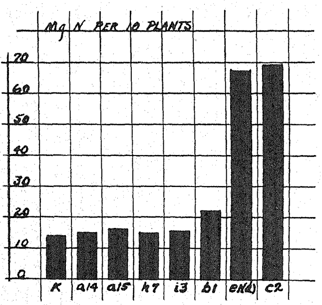

FIG. 9.—Nitrogen fixation by seven strains of *R. meliloti* on Fenugreek (*Trigonella Foenum-Graecum*).

Further study on the chemistry or physiology of the two groups of plants and also studies to determine if this hypothetical change in the bacteria is reversible would be interesting from the standpoint of the mechanism of biological nitrogen fixation.

From the practical standpoint these studies emphasize the necessity of using strains of the nodule bacteria isolated from burr clover and fenugreek for the successful inoculation of these legumes. They also stress the need of

more data on the performance of strains of bacteria from the nodules of each plant in a group on all legumes included in the same bacterial plant group.

SUMMARY AND CONCLUSION

Nitrogen-fixation studies of strains of *R. meliloti* on alfalfa, burr clover, sweet clover, and fenugreek revealed that the organism

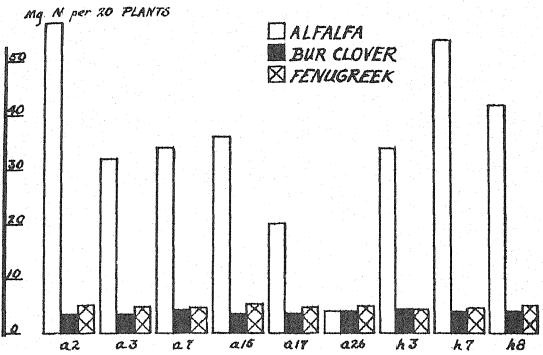

FIG. 10.—Nitrogen fixation by *R. meliloti* isolated from alfalfa and sweet clover.

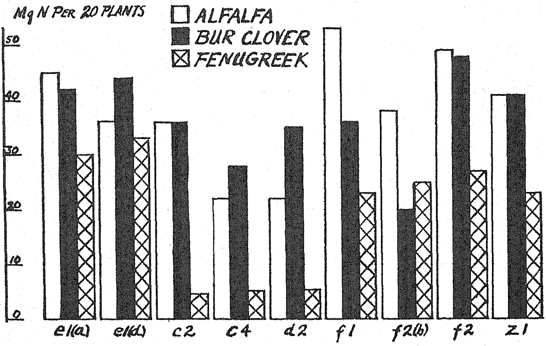

FIG. 11.—Nitrogen fixation by *R. meliloti* isolated from burr clover and fenugreek.

isolated from alfalfa and sweet clover failed to cause any significant fixation on burr clover or fenugreek. The strains of the bacteria isolated from burr clover or fenugreek showed an average percentage effective on all four host plants.

It was concluded that the bacteria living in association with alfalfa and sweet clover lose some component not necessary for high nitrogen fixation on these legumes but which is very necessary for fixation with burr clover and fenugreek. The nodule-forming capacity of the legume bacteria is not altered by association with any of the legumes studied.

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RELATIONSHIPS BETWEEN SOME MEASURES OF MATURITY IN MAIZE[1]

RALPH O. SNELLING AND IRWIN R. HOENER[2]

A STUDY of four methods of measuring maturity in maize was made in 1939. A planting of 218 strains and hybrids in a cooperative insect resistance project at McClure, in extreme southern Illinois, was used. The 218 entries consisted of 68 inbred lines, 125 single crosses, and 25 double crosses.

Data were obtained upon the number of days from planting to silking, the percentage of plants with husks bleached or showing a dry appearance on September 5, and the percentage of dry matter in the grain on September 14 and again at harvest on October 12. The silking date was recorded as the time at which 50% of the plants in the plot showed emerged silks. The percentage of plants with bleached husks was obtained by counts of plants with husks showing a dry yellowish appearance. The percentage of dry matter in the grain on September 14 was determined by the official A.O.A.C. method. Samples were obtained by removing a portion of the kernels from the middle section of 10 ears of each entry, from plants that appeared to have about average maturity. The percentage of moisture at harvest on October 12 was determined with the Tag-Heppenstall apparatus on a representative sample of shelled corn.

The data presented here were obtained from single plots of each entry. The inbred plots were single rows 10 hills long, while the single crosses and double crosses were in two-row plots, 10 hills long. Each of the three groups of material was grown in separate blocks arranged so as to minimize the effects of soil heterogeneity. The block of single crosses with 125 entries occupied an area 50 hills square.

The entries differed appreciably in their seasonal requirements, the range in number of days from planting to 50% silking being 56 to 75 days for the inbred lines, 54 to 69 days for the single crosses, and 60 to 69 days for the double crosses. The percentage of plants with bleached husks on September 5 varied from 0 to 100% for both the inbred lines and the single crosses, while the double crosses ranged from 3 to 69%.

The percentage of dry matter in the grain on September 14 ranged from 52 to 87 for the inbred lines, 55 to 84 for the single crosses, and 55 to 71 for the double crosses. The range in the percentage of dry

[1]Cooperative investigation between the Illinois Agricultural Experiment Station, Illinois Natural History Survey, Division of Cereal and Forage Insect Investigations, Bureau of Entomology and Plant Quarantine, and the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication April 4, 1940.

[2]Associate Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture, and Assistant in Soil Fertility, Department of Agronomy, Illinois Agricultural Experiment Station, respectively. Acknowledgment is due Ralph A. Blanchard, Division of Cereal and Forage Insect Investigations, Bureau of Entomology and Plant Quarantine, U. S. Dept. of Agriculture, and John H. Bigger, Illinois Natural History Survey, for obtaining portions of the data correlated here.

matter on October 12 was 76 to 90 in inbred lines, 81 to 90 in single crosses, and 83 to 88 in double crosses.

In Table 1 are given the coefficients of correlations computed among the different measures of maturity. In general, the correlations were highest in the single crosses and lowest in the double crosses. The correlations computed between silking date and percentage of plants with bleached husks on September 5 in the inbred lines and the single crosses were negative and highly significant. The coefficient of −0.415 in the double crosses was below the 1% level, but above the 5% level of significance.

TABLE 1.—*Correlations between different measures of maturity of inbred lines, single-cross, and double-cross hybrids.*

Correlation between	Calculated r		
	Inbred lines	Single crosses	Double crosses
Days from planting to silking, and percentage of plants with bleached husks on Sept. 5	−0.514	−0.676	−0.415
Days from planting to silking, and percentage of dry matter in grain, Sept. 14	−0.603	−0.814	−0.735
Days from planting to silking, and percentage of dry matter in grain, Oct. 12	−0.325	−0.539	−0.182
Percentage of plants with bleached husks on Sept. 5, and percentage of dry matter in grain on Sept. 14	0.692	0.648	0.514
Percentage of plants with bleached husks on Sept. 5, and percentage of dry matter in grain on Oct. 12	0.484	0.511	0.353
Percentage of dry matter in grain on Sept. 14, and percentage of dry matter in grain on Oct. 12	0.560	0.598	0.478
D. F.	66	123	23
Significant r (1% level)	0.317	0.230	0.505

The correlations computed between silking date and percentage of dry matter in the grain on September 14 were negative and highly significant in all three groups. The correlations of −0.814 in the single crosses and −0.735 in the double crosses indicate a closer relationship between these two measures than between any of the others. In the inbred lines the correlation was slightly greater between the percentage of plants with bleached husks on September 5 and the percentage of dry matter on September 14.

The correlation of −0.182 between silking date and percentage of dry matter at harvest on October 12 was not significant in the double crosses even on a basis of a 5% level. This is of special interest because both criteria are used extensively in measuring the maturity of commercial hybrid corn. If there is in general as little relationship between these two characters as appears from these studies with double crosses, the number of days from planting to 50% silking and the percentage of dry matter at harvest should not be regarded as equal measures of maturity. However, it is probable that in years when the corn is not so dry as in 1939, the relationship might be greater. The dry matter content of the double crosses on October 12 was rather uniform, ranging only from 83 to 88%. The extended dry

weather of 1939 doubtless reduced the moisture content of many of the later-silking strains of corn below that usually carried by these strains in more normal seasons.

The percentage of plants with bleached husks at the approach of maturity seems to be an indication of the percentage of dry matter in the grain at that time as highly significant correlations were obtained among both inbred lines and single crosses. The correlation for the double crosses was about equal to the 1% level of significance for 23 degrees of freedom. These data were obtained under conditions where the ear-shanks were relatively free from Diplodia and other pathogenic infections. However, it is believed that this relationship would not be materially affected under conditions where the ear-shanks are diseased, since loss of moisture in all ear parts seems to be associated with diseased shanks.

The percentage of plants with bleached husks on September 5 showed less correlation with the percentage of dry matter on October 12 than on September 14, although significant coefficients were obtained in the inbred lines and the single crosses. The correlation of 0.353 for the double crosses is below the 5% level of significance.

The coefficient of correlation between the percentage of dry matter on September 14 and on October 12, was large enough to be considered significant for the inbred lines and single crosses, and greater than the 5% level of significance for the double crosses.

DISCUSSION

Dry matter content of the grain at a proper stage of development is probably the best measure of relative maturity. It is self-evident that a "proper stage" is one at which a wide range in dry matter content is found between the earliest and latest maturing strains being compared. This stage will vary, as to date of occurrence, with seasonal conditions. For example, in the present study in 1939, October 12 was not a suitable time, because all strains had reached fairly uniform dry matter content. On September 14 the range in dry matter content was fairly wide, and for this reason the stage of development on that date was a more suitable one for comparisons of relative maturity.

Having established a basis of comparison, the other methods tried may now be evaluated. Correlation coefficients indicate that both number of days from planting to silking and the percentage of plants with bleached husks are satisfactory indices of relative maturity, the former being slightly better than the latter *in the season under consideration*. Dry matter content on October 12 is a poor index of relative maturity for reasons previously given.

It is well to recognize that unusual environmental conditions may alter the value of the different measures of maturity. For instance extreme drouth or hot winds while the corn is in the milk stage would encourage premature drying and as a result all strains would reach a rather uniform moisture content at approximately the same time even though they were not in a true sense mature.

SUMMARY

In a study of indices of relative maturity of corn grown in 1939, coefficients of correlation were calculated among the number of days from planting to 50% silking, percentage of plants with bleached husks on September 5, and percentage of dry matter in the grain on September 14 and at harvest on October 12.

A total of 218 entries were used in this study, including 68 inbred lines, 125 single crosses, and 25 double crosses.

In general the correlations were highest among the single crosses and lowest among the double crosses.

The most significant correlations were between silking date and the percentage of dry matter on September 14, while the least significant was between silking date and dry matter at harvest time (October 12) in the double crosses. This indicates that the percentage of dry matter at harvest time may not be closely associated with the number of days to silking in double crosses that are as thoroughly dried at harvest as they were following the dry weather of 1939.

The significance of these various indices of relative maturity is discussed.

A QUALITATIVE COLOR TEST FOR THE MONTMORILLONITE TYPE OF CLAY MINERALS[1]

STERLING B. HENDRICKS AND LYLE T. ALEXANDER[2]

MONTMORILLONITE is one of the several clay minerals often found in the clay fraction of soils and its identification is important in problems of soil genesis. During the study of some organic salts of montmorillonite it was observed that characteristic color reactions were given by certain aromatic diamines. Further investigation has shown that these color reactions can be used as qualitative tests for montmorillonite in the presence of other clay minerals and constituents of soils, but in the absence of organic matter.

THEORY OF REACTION

A typical reaction is that of benzidine or its hydrochloride which give deep blue colors when added in dilute solution to suspensions of montmorillonite such as the commercially available volclay or Mississippi materials. The color is apparently due to fortuitous oxidation of a very small amount of the diamine to the semiquinone form which is known to be an "odd electron" compound. Other diamines that can be oxidized to semiquinone forms give the colors of these forms when added to most montmorillonite suspensions.

Discussion of the nature of these colored compounds is closely connected with color theories for triphenylmethane dyes and Wurster's salts.[3] It was first thought that the Wurster salts were molecular compounds between the oxidized and reduced forms of the molecule[4] to which the name meriquinoid was given by Willstätter. The extensive work of Michaelis and his collaborators, however, has shown that the colored forms are monomolecular[5] in most cases and are typical odd electron compounds. Thus Wurster's red salt which is obtained by oxidation of *asymm*-dimethyl-p-phenylene-diamine is shown to be a resonance hybrid of two odd electron forms (Fig. 1).

All diamines tested that were known to give semiquinone forms on oxidation gave the corresponding colors when added to montmorillonite suspensions. These were:

o-phenylene diamine	red
p-phenylene diamine	blue
benzidine	blue

[1]Contribution from the Fertilizer Research Division, Bureau of Agricultural Chemistry and Engineering, and the Soil Chemistry and Physics Division, Bureau of Plant Industry, U. S. Dept. of Agriculture. Received for publication April 5, 1940.

[2]Senior Chemist and Chemist, respectively.

[3]Note "Sidgwick's Organic Chemistry of Nitrogen," T. W. J. Taylor and W. Baker, p. 82 ff., London, 1937 for a discussion of the structure of these dyes.

[4]KEHRMANN, F. On some colored and colorless diimines. Berichte, 38:3777–3778. 1905.

[5]MICHAELIS, L. Semiquinones, the intermediate steps of reversible organic oxidation-reduction. Chem. Rev., 16:243–286. 1935. PAULING, L. Nature of the Chemical Bond. 1939. (Pages 256–263.)

assym-dimethyl-p-phenylene diamine........red
tetraethylparaphenylenediamine............blue
2–7 diamino fluorene......................blue
2–5 diamino fluorene......................blue

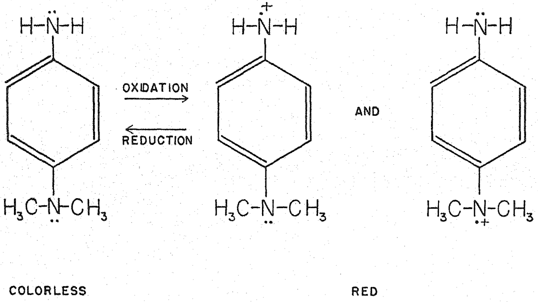

FIG. 1.—Forms of Wurster salts.

Aromatic diamines such as m-phenylene diamine that cannot be oxidized to semiquinones did not give color reactions with montmorillonite and this is also true of a large number of monoamines.

The colored form was strongly attached to the montmorillonite, presumably replacing an exchangeable ion. It does not noticeably fade over a period of 6 months after the clay has dried and is not unstable in solution. Attempts to exclude oxygen, by prolonged boiling in an atmosphere of nitrogen, so thoroughly as to prevent oxidation have not been successful. It is probable that the oxidation is due to the presence of ferric iron or an equivalent oxidizing agent in an insoluble form together with or a part of the montmorillonite. Very pure samples of montmorillonite such as the material from the Island of Ponza and some specimens from Otay, California, gave only very faint blue colors with benzidine due apparently to the absence of iron compounds. Freshly prepared $Fe(OH)_3$ and the iron compounds present in soils did not give semiquinones in the absence of montmorillonite. Presence of manganese dioxide interferes with the test by action as an oxidizing agent. Ferrous iron or other reducing agents in solution prevent development of the semiquinones in the presence of montmorillonite.

The following experiment shows that the color development depends upon formation of a salt between the benzidine and montmorillonite. About 2 millimols of codeine or brucine is added to a suspension of a gram of montmorillonite such as commercial volclay (base exchange capacity 0.9 M. E. per gram). Benzidine added to the resulting system gives only a faint blue color, while a deep blue quickly develops in the absence of the alkaloid. The explanation is that the

large and more basic alkaloid molecule is far more firmly held as a cation than is benzidine and thus prevents formation of the latter salt. This experiment also demonstrates that the presence of an oxidizing agent alone in the clay is inadequate for the test.

RESULTS WITH MINERALS AND SOILS

An extensive series of tests were carried out with ortho- and para-phenylenediamines on several samples each of various pure and impure clay minerals. No color reactions were obtained with halloysite, hydrated halloysite, kaolinite, kaolinite ground for 12 days, and glauconite. Negative results also were obtained with silica gel, glaucosil (silica obtained by acid leaching of greensand), goethite, hematite, and sericite. Seven of eight bentonite samples supplied by Dr. R. E. Grim of the Illinois Geological Survey gave various shades of pink, red, and brown with o-phenylenediamine and dark to very dark blue with p-phenylenediamine. The eighth sample, from Hot Springs Co., Arkansas, which was marked as questionable material did not give a color reaction with either diamine. This also was the case with two samples of magnesium bentonite from Hector, California, one of which was the described material and the other a sample of commercial "eyrite". Magnesium bentonite is known to differ from the usual montmorillonite in other properties and to be very free of iron-bearing impurities. Positive results were obtained with other montmorillonite and nontronite specimens.

Clay fractions of several soils for which thorough mineralogical analyses had been made were tested with benzidine.[6] Positive results were obtained only for Miami C10343, Carrington C10086, Barnes C10307, and a desert soil C3420. Montmorillonite had been previously identified only in the clay fraction of the Carrington and Barnes soils. The clay fraction of the Miami and desert soils, however, contained large amounts of hydrous mica which readily grades into a mixed layer mineral with montmorillonite as a component. For the last few months the test has been used together with the differential thermal analysis method on a number of clay fractions from soils and has been found to be completely trustworthy in the absence of organic matter.

Recent experiments in the field have shown that organic matter frequently gives the test. Unless it is removed the test is limited to horizons containing only small amounts of organic matter. Removal of this matter is a simple procedure in the laboratory by means of oxidation with hydrogen peroxide but may cause trouble in the field and thus limit the applicability of the test. Organic matter from different sources varied greatly in development of color with benzidine solutions.

Benzidine hydrochloride is recommended for use in applying the test. The solid can readily be obtained and is stable when kept in a brown bottle. Solutions slowly oxidize but can be used after standing

[6]ALEXANDER, L. T., HENDRICKS, S. B., and NELSON, R. A. Minerals present in soil colloids: II. Estimation in some representative soils. Soil Sci., 48:273–279. 1939.

for 2 months in brown glass. The blue color is not obscured by iron-bearing minerals of most soils. It is not necessary to separate the clay fraction but some advantage is gained by a single decantation from coarse material. Small amounts of montmorillonite in red or brown soils give green and greenish-blue colors as would be expected. The hydrogen-ion concentration is not critical, but in moderate acid concentrations green colors are obtained.

HOW TO MAKE THE TEST

Organic matter, if present in quantities sufficient to interfere, should be decomposed by treatment with moderately strong hydrogen peroxide and this removed by evaporation to dryness at less than 100° C. Benzidine or its hydrochloride either as solid or in water solution is added. A few milligrams of the solid or a few cc of the saturated solution are added when added to a few grams of soil. The blue or greenish-blue color characteristic of the montmorillonite type of clay mineral may develop rather slowly at room temperature. Warming will hasten the reaction, but it is best to allow the mixture to stand for several hours in any case.

The test is now being tried by the U. S. Soil Survey, the U. S. Geological Survey, the U. S. Bureau of Mines, and various university laboratories. It is a pleasure to acknowledge the cooperation of these organizations. Dr. L. Michaelis of the Rockefeller Institute for Medical Research kindly supplied samples of several diamines.

CONCLUSIONS

Organic diamines that can be oxidized to semiquinone forms undergo catalytic oxidation in the presence of the clay mineral montmorillonite. Since the oxidized forms are highly colored their production can be used as a simple qualitative test for montmorillonite in soils. Kaolinitic clay minerals and other inorganic constituents of soils give negative results. Organic matter, however, frequently gives the test which limits its simple application in the field.

DORMANCY IN FATUOID AND NORMAL OAT KERNELS[1]

F. A. Coffman and T. R. Stanton[2]

THE widespread occurrence of fatuoid or false wild oats (Fig. 1) is generally recognized by plant scientists familiar with oats. The nature of their origin has been the object of controversy for many years and the problem has been attacked from the genetic, the cytologic, and the physiologic standpoints. Two theories have been advanced to explain their occurrence. One theory assumes that fatuoids result from mutation and the other that they result from natural crossing, probably with wild oats (*Avena fatua*). Each theory has many adherents and the literature on genetic and cytologic studies on this subject is so extensive that no attempt is made to review it at this time. Stanton, Coffman, and Wiebe (8)[3] and more recently Coffman and Taylor (1) have presented rather complete reviews of the literature on these subjects.

Physiologic studies of these aberrant oats have been limited. The well-known observation that freshly harvested seed of *Avena fatua*, the common wild oat, frequently does not germinate promptly is supported by ample data. It is largely this character of dormancy that tends to make the wild oat a noxious weed. However, very few data on the dormancy of fatuoids or of cultivated oats are available. Fischer (5) and Criddle (3) report that fatuoids germinated in the autumn while wild oats normally do not.

Garber and Quisenberry (6) studied delayed germination in seed of wild and false wild oats and of hybrids between wild and cultivated oats. They concluded that seeds of *Avena fatua* and some of its hybrids possessed the property of delayed germination but found no evidence of delayed germination in seed from homozygous false wild oats, heterozygous false wild, or from *A. sativa* varieties. Their physiologic studies were limited to seed of only three varieties of *A. sativa*, namely, Victory, Garton No. 748, and Aurora.

Deming and Robertson (4) observed dormancy in Kanota oats (*Avena byzantina*) but little, if any, in the two varieties of *A. sativa*, Nebraska 21, and Colorado No. 37, which they tested.

Johnson (7) reported dormancy studies of *Avena fatua* which indicated "Great variations . . . in the after-ripening periods of a number of *A. fatua* selections".

Coffman and Stanton (2) tested for dormancy the freshly harvested seed of 25 distinct varietal types belonging to six species and subspecies. They observed indications of dormancy in seed of varieties of *Avena byzantina*, *A. fatua*, and *A. sterilis*. A single variety of *A. nuda* germinated promptly. Varieties of *A. sativa* and *A. sativa orientalis* differed, some being prompt and others more or less delayed in germination.

[1]Contribution from the Division of Cereal Crops and Diseases, U. S. Dept. of Agriculture. Received for publication April 8, 1940.

[2]Agronomist and Senior Agronomist, respectively.

[3]Numbers in parenthesis refer to "Literature Cited," p. 466.

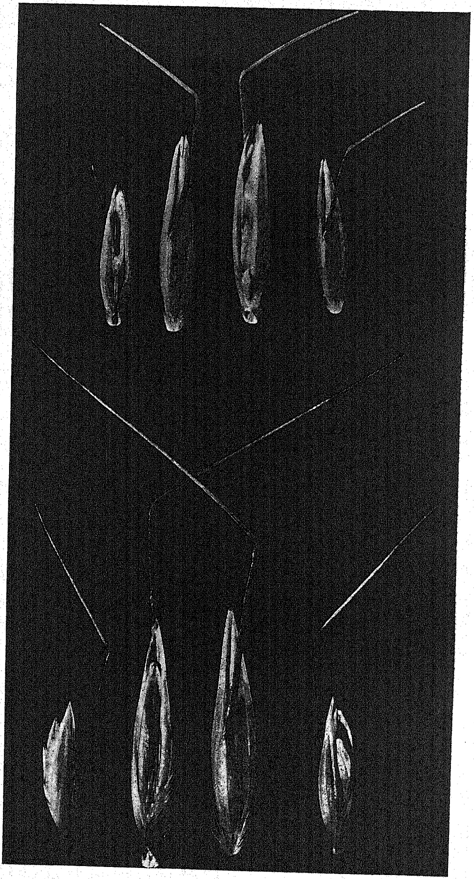

FIG. 1.—*Upper*, fatuoids from the *Avena sativa* variety Victory; *lower*, fatuoids from the *A. byzantina* variety Fulghum.

In view of the fact that fatuoids occur in so many oat varieties and that oat varieties differ as to dormancy or after-ripening of their seed, it is of interest from the standpoint of the origin of fatuoids to determine the relationship, if any, between the promptness of germination of freshly harvested fatuoids and that of seed of the respective variety in which the fatuoids occur. This study was suggested by J. H. Martin of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Dept. of Agriculture.

MATERIALS AND METHODS

Two separate experiments were conducted to determine dormancy in fatuoid and normal oats. In one the seed was obtained from plants grown in the greenhouse and germinations were made in a standard germinator in the laboratory at approximately room temperature, or about 65° to 70° F. The seed used in this test was collected in 1937 from several varieties in different parts of the United States. In each case, normal or typical panicles from neighboring plants were collected for comparison. Seed from aberrant and normal plants of each variety was sown in pots in the greenhouse at Washington, D. C. Usual greenhouse technic was followed in growing the plants, and when mature the plants were harvested, the panicles threshed, and the seed put into the germinator immediately.

In the second experiment the fatuoid and normal oats were collected from plots and nursery rows on the Aberdeen Substation, Aberdeen, Idaho, in 1938. The fatuoid plants, together with adjacent normal plants, were gathered when the oats were mature. The seed was threshed immediately and placed between moistened blotters which were rolled in cloth bags. These were placed in a basement laboratory at a comparatively uniform temperature of about 65° to 70° F and were kept moist. In all cases, seed from a single plant constituted a sample, which was necessary in order to detect any heterozygosity among different fatuoid individuals from the same variety. Frequently this necessitated testing samples of comparatively few seeds. The samples usually, although not always, contained 25 seeds. With few exceptions, germination counts were made at 3-day intervals. In all tests any seed showing a protruding coleoptile was considered as having germinated.

EXPERIMENTAL DATA

Data are presented from 29 homozygous and 10 heterozygous fatuoids as compared with those from 33 plants of the normal type of the parent varieties. Tests were made on fatuoids from 16 different varieties, 4 classed morphologically as belonging to *Avena byzantina* and 12 as belonging to *A. sativa*. In the *A. sativa* group fatuoids from early, midseason, and winter oat varieties of *A. sativa* were tested, but in *A. byzantina* the varieties represented were all early.

The germination of seeds from 21 homozygous and 4 heterozygous fatuoids was compared with that from normal plants in the greenhouse at Washington, D. C., and 9 homozygous and 5 heterozygous fatuoids were compared with normal plants of the respective varieties in the experiments at Aberdeen, Idaho.

TESTS ON SEED GROWN IN GREENHOUSE

The data in Table 1, except for one sample, show very slow or delayed germination of freshly harvested seed from both fatuoid and

TABLE 1.—*Germination of freshly harvested normal oats and fatuoid oats collected from the same varietal plots in seed grown in the greenhouse.*

Variety	C. I. No.	Collection No.	% normal germination after					% fatuoid germination after				
			6 days	13 days	18 days	27 days	34 days	6 days	13 days	18 days	27 days	34 days
Avena byzantina, early												
Frazier.......	2381	1	0	—	20	30	—	25	—	75†	—	—
Kanota......	839	1	30	—	40	—	—	50	—	—	—	—
Kanota......	839	1*	—	—	—	—	—	90	95	—	—	—
Avena sativa, early												
Richland.....	787	1	32	—	40	72	84	80	100	—	—	—
Iogold.......	2329	1	0	—	27	62	100	50	—	90	100	—
Iogold.......	2329	2	80	—	—	—	96	28	44	80	84	—
Iogold.......	2329	3	75	80	85	—	100	12	37	—	49	61
Boone.......	3305	1	100	—	—	—	—	100	—	—	—	—
Boone.......	3305	2	72	92‡	—	—	—	75	87†	—	—	—
Boone.......	3305	3	87	100	—	—	—	75	100	—	—	—
Boone.......	3305	3*	—	—	—	—	—	90†	—	—	—	—
Early Joanette	1092	1	0	—	—	—	—	—	—	—	—	—
Early Joanette	1092	1*	—	—	—	—	—	5	—	—	—	—
Markton × Iogold.......	3352	1	96	100	—	—	—	95	100	—	—	—
Bond × Iogold	——	1	100	—	—	—	—	90†	—	—	—	—
Avena sativa, midseason												
Abundance...	755	1	100	—	—	—	—	100	—	—	—	—
Abundance...	755	1*	—	—	—	—	—	100	—	—	—	—
Bannock.....	2592	1	100	—	—	—	—	100	—	—	—	—
Bannock.....	2592	2	100	—	—	—	—	80	100	—	—	—
Bannock.....	2592	3	100	—	—	—	—	96	100	—	—	—
Bannock.....	2592	4	100	—	—	—	—	98†	—	—	—	—
Bannock.....	2592	5	100	—	—	—	—	94	—	98†	—	—
Bannock.....	2592	6	100	—	—	—	—	100	—	—	—	—
Bannock.....	2592	7	100	—	—	—	—	—	—	—	—	—
Bannock.....	2592	7*	—	—	—	—	—	70	80	95†	—	—
Swedish Select	134	1	100	—	—	—	—	100	—	—	—	—
Swedish Select	134	2	100	—	—	—	—	70	100	—	—	—
Avena sativa, winter oat												
Lee.........	2042	1	40	100	—	—	—	80‡	—	—	—	—

*Intermediate fatuoid.
†One seed rotted.
‡Two seeds rotted.

normal plants in the two varieties of red oats, Kanota and Frazier. These results are not wholly conclusive because the number of fatuoid seeds from the greenhouse cultures of both varieties was small. A test of seed from fatuoids and normal plants of Coker 33-15, a third red oat variety, was started but unavoidable conditions prevented its being completed. However, after the seed had been in the germinator for 13 days the germination for the different collections of that variety varied from 0 to 37% for the fatuoids, 0 to 28% for the intermediate fatuoid forms, and from 0 to 20% for the normals. These results indicate that there is no difference in the time of germination of fatuoid and normal seeds of Coker 33-15. This variety undoubtedly germinates slowly.

It will be noted that, in general, rather slow germination was shown by both Richland and Iogold. Germination of all the seeds had not occurred even at the end of the thirty-fourth day after being put in the germinator. These varieties showed some difference in germination between the fatuoid and normal oats. The slow germination of both Richland and Iogold conforms with results obtained by Coffman and Stanton (2).

Except for Early Joanette, all the remaining varieties of common oats showed very prompt germination. This was true of fatuoid, intermediate, and normal oats. This rapid and complete germination of all seeds of varieties such as Swedish Select, Bannock, Abundance, Boone, and the homozygous selections from the two hybrid combinations indicates rather definitely that fatuoids conform in time of germination with that of the cultivated or normal populations in which they occur. The very prompt germination of these varieties may have been favored by allowing them to remain in the greenhouse a little longer after maturity than in the case of the Richland and Iogold varieties. However, even when ample allowance is made for some after-ripening, there is no doubt that varieties such as Bannock and Swedish Select germinate promptly.

Lee was classed by Coffman and Stanton (2) as being slow in germination, but in the present test Lee germinated rather promptly. Early Joanette showed delayed germination, thus agreeing with the results on this variety published by these investigators.

STUDIES OF FIELD-GROWN SEED

In the tests (Table 2) conducted at Aberdeen, Idaho, there was a tendency for seed of all varieties to be somewhat slower to start germinating than was found by Coffman and Stanton (2) in their tests of dormancy conducted on greenhouse-produced seed. The reason is not known. The data obtained indicate, however, that some variation may occur in the promptness of germination of seed from different plants of the same variety. Victory, for example, was classed by Coffman and Stanton (2) as "prompt" in germination, but a difference of several days occurred in the initial germination recorded on seed from different plants of that variety in tests conducted on field-grown seed at Aberdeen, Idaho.

Freshly harvested seed from both the fatuoid and the normal plants of the Fulghum variety (*Avena byzantina*) was decidedly slow

TABLE 2.—*Germination of freshly harvested seed of normal oat plants and fatuoid plants collected from the same plots at Aberdeen, Idaho, in 1938.*

Variety	C. I. No.	Collection No.	% normal germination after 4 days	7 days	10 days	14 days	18 days	22 days	27 days	30 days	40 days	% fatuoid germination after 4 days	7 days	10 days	14 days	18 days	22 days	27 days	30 days	40 days
							Avena byzantina, early													
Fulghum	708*	1	0	—	—	—	—	—	—	—	90	—	—	—	—	—	—	—	—	—
Fulghum	708	1†	—	—	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	10
Fulghum	708	2	0	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	—	—
Fulghum	708	2‡	—	—	—	—	—	—	—	—	—	0	10	—	—	—	30	—	—	60
Fulghum	708	3	0	—	—	—	—	—	—	—	40	0	—	—	—	—	—	—	—	40
Fulghum	708	4	—	—	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	10
Fulghum	708	5	—	—	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	25
Fulghum	708	5	—	—	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—	30
							Avena sativa, midseason													
Abundance	755	1	0	—	36	70	100	—	—	—	—	—	—	—	—	—	—	—	—	—
Abundance	755	1†	—	—	—	—	—	—	—	—	—	0	—	15	—	75	85	—	—	—
Abundance	755	2	0	10	15	55	65	90	—	—	—	0	10	35	75	—	90	95	100	—
Abundance	755	3	0	—	10	85	100	—	—	—	—	0	4	16	60	84	92	—	—	—
Andrew A	2239	1	0	—	15	60	72	80	84	92	100	0	60	75	100	—	—	—	—	—
Victory	2020	1	0	5	85	95	—	—	—	—	—	0	—	45	80	95	—	—	—	—
Victory	2020	2	0	—	45	75	85	95	—	—	—	—	—	—	—	—	—	—	—	—
Victory	2020	2†	—	—	—	—	—	—	—	—	—	0	10	80	100	—	—	—	—	—
Victory	2020	3	0	20	73	94	100	—	—	—	—	—	—	—	—	—	—	—	—	—
Victory	2020	3†	—	—	—	—	—	—	—	—	—	0	10	60	80	—	90	—	—	—

*All samples of C. I. 708 were taken from one plot.
†Intermediate fatuoid.
‡Black-kerneled intermediate fatuoid.

in germinating. Only one sample showed any germination after 30 days. This sample from an intermediate fatuoid plant had germinated 10% by the seventh day following harvest and 30% 22 days after harvest. By the end of the test (40 days) it had germinated 60%. One sample of Fulghum germinated reasonably well (90%) during the course of the test, while another showed no germination after 40 days in the germinator. Both fatuoid and normal seeds of the Fulghum variety were decidedly delayed in germination.

In the tests of varieties of *Avena sativa* three comparisons were made between seed of fatuoid and normal plants of the Abundance variety. One fatuoid and one cultivated sample did not start germinating until the tenth day after harvest. Germination in all others had started by the seventh day, and all samples, both fatuoid and normal, germinated more than 90% by 27 days following harvest. Consequently, no dormancy was evident in either the normal or fatuoid seed.

One fatuoid from the *Avena sativa* variety Andrew A was compared with normal seed of that variety. The fatuoid seed germinated 60% 7 days following harvest and 100% by the fourteenth day, whereas the cultivated or normal seed had germinated 15% by the tenth day and 100% of the kernels had germinated 40 days following harvest. Here normal seed showed a greater tendency toward dormancy than the fatuoid seed.

Three pairs of comparisons were made with normal and fatuoid oats from the *Avena sativa* variety Victory. This variety was classed as prompt in germination by Coffman and Stanton (2). Two samples each of the normal and fatuoid seeds had started germinating by the seventh day and all three were partially germinated by the tenth day. All samples from the Victory variety, both cultivated and fatuoid, had germinated 75 to 100% by the fourteenth day and all finally germinated 90 to 100%. Consequently, no evidence of dormancy was observed in seed of either normal or fatuoid from Victory.

SUMMARY

Freshly harvested seed of fatuoid and normal oat plants from 12 varieties of *Avena sativa* and 4 varieties of *A. byzantina* was tested to determine the relationship in dormancy between fatuoid and normal plants of the same variety. Comparisons were made of seed grown both in the field and greenhouse.

In the tests made when dormancy occurred in the normal plants of a variety of oats it also occurred in fatuoids from that variety, and when germination was prompt, the seed of the fatuoid of either the homozygous or the heterozygous intermediate plant forms also germinated promptly. This seems to furnish evidence for the belief that fatuoids result from mutations rather than from natural crosses with *Avena fatua* inasmuch as the seed of the latter usually has a decided tendency toward dormancy.

The experiments also indicated that characters associated with fatuoids, such as the "suckermouth" form of base, the presence of basal hairs on the callus, etc., were unrelated to dormancy in oats.

Coffman and Stanton (2) observed previously that these kernel characters were often found in oat varieties having a tendency to dormancy but stated that their association with dormancy might be merely accidental.

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THE USE OF CLASS WORDS IN AGRONOMY[1]

WILBERT W. WEIR[2]

SCIENTIFIC agricultural literature reveals much confusion in the use of class words, that is, words that stand for classes of things. There seems to be much confusion in the use of the terms "species," "genus," "soil type," and "soil series." Apparently the fact that all class names are general words, and hence abstract,[3] is too often overlooked. Moreover, it is common to see a class word used as though it named something that has materiality. Careless use of class words and their confusion with collective nouns, with nouns that have the same form in the plural as in the singular, and with mass words may make difficult a clear understanding of the meaning intended.

The terms "large species" and "small species" appear often. What is meant? Small and large genera embrace few and many species (classes). Small and large *species*, on the other hand, cannot imply species that embrace few and many classes, respectively. When plants are considered, small species would mean plants that naturally make short height growth, as compared with plants of other species of the same genus.

It is commonly stated that *the soil* is a specific object in nature, and that it may be divided into many groups, soil series being the most important. Such a statement implies that, as a material object, "the soil" has individual character in the sense that the earth has, for example. If this were so, would soil classification consist in dividing "the soil" as unity into various parts, and then grouping these parts into series? Logically, how can this be? Soil classification assumes the existence of individual soils as earthy bodies, and these earthy bodies are classed, in general, as *soil*. In natural classification, soils are first grouped according to their similarity into type classes; and type classes, in turn, are grouped according to identical characteristics into larger classes called series; and series, into family groups, and so on.

A keen observer of natural phenomena wrote that he "saw *Crotalus atrox* at an elevation of 8,000 feet." Here a Latin or scientific class word, which is abstract, has been used as though it named something that had individual character. Specifically, rattlesnakes of the species *Crotalus atrox* were seen. In this instance, a clear statement of fact that would be appreciated by laymen and others who do not know snake classification would be, "Western diamond rattlesnakes of the species *Crotalus atrox* were seen at an elevation of 8,000 feet."

Recently there appeared an article on "germination of *Quercus alba* and *Juglans nigra*." The meaning intended was the germination of white-oak acorns and nuts of black-walnut trees.

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[1]Contribution from the Southwestern Forest and Range Experiment Station, U. S. Forest Service, Tucson, Ariz. Received for publication April 9, 1940.

[2]Forest Ecologist.

[3]See under "Abstract, 3, b" and "Abstraction, 3" in recent editions of Webster's New International Dictionary.

SPECIFIC VS. GENERAL WORDS

According to Weseen,[4] authorities on rhetoric warn against the excessive use of general words, that is, words that stand for whole classes of objects or actions. It is generally accepted that thought can best be expressed by specific words, because they are more accurate, clearer, and more interesting. Specific words tell something definite. No doubt most students of rhetoric have seen sentence comparisons like the following: (General words.) "The man went to see the group." (Specific words.) "The hunter hobbled to gaze at the dancers."[5] Compare also the following two sentences: Soil reaction affects soil organisms. Soil acidity may retard the activity of azotobacters.

In the sentence, "In some places poisonous *Drymaria* is getting more abundant," *Drymaria* is the name of a genus of plants that occur on some southwestern ranges. Those of the species considered are poisonous. Poisonous *Drymaria* certainly does not name a crop. If it did, it would be used as a collective noun, as are the words "corn" and "cotton." Nor is it a plural singular, that is, a noun that has the same form in the plural as in the singular, like the words "deer" and "grouse." In the above sentence, the phrase "in some places" calls for a specific word. The thought also calls for specific words, because the plants included in the genus "*Drymaria*" are not all confined to the few places where they are increasing in number. They occur in other places also, but in the other places they may not be on the increase. A clear, logical statement of the fact would be, "In some places poisonous drymarias are increasing in number," just as one would say that in some soils rhizobia are increasing in number, or that in some soils actinomycetes are less numerous than protozoans.

CLASS WORDS DESIGNATE KINDS

Sometimes it is convenient to express thought in the form of lists. In lists, likewise in classifications, kinds are briefly stated. Hence, lists that designate kinds should be built with class words, for *class* means kind.

Ordinarily, in scientific agricultural writings, common class names are given preference in designating kinds. But when a common class name for the plants of a genus or of some higher class is lacking, a common name may be derived from the Latin or Greek class name. The name thus derived is not italicized.[6] In biology most such derived names are not capitalized. Some such names, particularly in soil science, retain the capital letters. Series in soil classification, for example, are given geographic names, and hence they retain the capital letters. Webster's New International Dictionary (recent editions) has become a valuable aid in the use of scientific class names and of English names (of plants or animals of the class) derived therefrom. To illustrate:

[4]Crowell's Dictionary of English Grammar, by Weseen. New York. 1928.
[5]*idem.*
[6]The scientific names of genera, subgenera, species, and sub-species (varieties) are italicized, whereas the names of classes of higher rank are not.

Scientific class name (Abstract)	Individual thing (Concrete)	Individuals plural form (Concrete)
Poinsettia	a poinsettia	poinsettias
Rhizobium	a rhizobium	rhizobia
Azotobacter	an azotobacter	azotobacters
Actinomyces	an actinomycete	actinomycetes
Norfolk loam	a Norfolk loam	Norfolk loams
Protozoa	a protozoan	protozoans
Leguminosae	a legume	legumes
Chernozem (soils)	a chernozem	chernozems

Ordinarily, in biology, a simple rule to follow in capitalization of scientific class names and the names of the natural objects concerned is that the name of a genus or of a higher class is capitalized when used as a scientific class name, but is written with a lower-case letter when used as a common English class name and also when used to name a plant, an animal, plants, or animals of the genus or of the higher class.[7]

A list may be built entirely of scientific class words (purely technical list), or it may include names of various classes that belong to the different categories of the classification considered. Ordinarily, specific kinds of plants are indicated by the English, or common, class names, supplemented (in parentheses) with scientific class names, usually of species or genera, as white oaks (*Quercus alba*). With respect to the common names, more than one kind of any particular class may be indicated by the plural form of the common, or English, class word. Whether more than one species are considered in each case may be indicated (in parentheses) in either of the following three ways: (1) by the names of the species considered, (2) by the abbreviation "spp." after the name of a genus, or (3) simply by the name of the genus or of some higher class without the abbreviation "spp.," as shown in the following example:

The plants studied were of the following kinds:

gramas (*Bouteloua eriopoda*, *B. trifida*) [Two species of grasses.]
pines (*Pinus strobus*, *P. resinosa*) [Two species.]
wheat (*Triticum vulgare*) [One species.]
beans (*Phaseolus vulgaris*) [One species.]
cacti (*Opuntia* spp.) [Several species.]
tobaccos (*Nicotiana*) [All species.]
rhodendrons (*Rhododendron*) [All species.]

CLASS WORDS IN DISCOURSES

In discourses, as well as in sentences that may be necessary to insert in lists, clear expression of thought usually calls for the names of the objects considered rather than for names of their classes. In discourses, class words are probably of most value in enabling one to refer to natural objects by kinds. Such use can help one over certain

[7]Rule suggested, in correspondence, by Dr. J. P. Bethel, of G. &. C. Merriam Company, publishers of Webster's New International Dictionary.

rough places, especially when it may be necessary to include some scientific class names when common names are lacking. Moreover, in a series of names, it is conceded as good form by authorities on rhetoric to have specific or "thing" names keep company with specific names, and to have class words keep company with class words. To illustrate: (Not an approved form.) "We found yuccas, burroweed, and some paloverde." In this sentence the word "yuccas" refers to specific plants, whereas "burroweed" and "paloverde" are common names of classes of plants. Approved usage could be either "yuccas, borroweeds, and a few paloverdes," or if in each case the plants are of a single species, "plants of such kinds as yucca, burroweed, and paloverde."

Two examples of approved usage follow: (1) There were plants of such kinds as yuccas (*Yucca* spp.) and mesquite (*Prosopis juliflora*). (2) In that area are pines (*Pinus ponderosa*), spruces (*Picea engelmannii* and *P. parryana*), and a few scattered junipers (*Juniperus monosperma*); whereas in an adjoining area there are a few ponderosa pines and also grasses and shrubs of such kinds as fescues (*Festuca* spp.), needlegrasses (*Stipa* spp.), junegrass (*Koeleria cristata*), muhly grasses (*Muhlenbergia*), Apache-plume (*Fallugia paradoxa*), and *Oryzopsis*.

It is of interest to note that lexicographers and authorities on rhetoric do not regard words like "pine," "oak," and "coffee," as collective nouns nor as plural singulars. However, such terms may be used as mass words[8] when reference is made to something that may be considered as uncountable units, as, "He deals in pine," meaning pine building materials. However, the word "pine" may be used in the plural when reference is made to pine seedlings or trees (as several pines) and to kinds (as two kinds of pines).

In purely technical papers, scientific class names are commonly used for the exact designation of organisms, plants, and animals when they have no common names, as ". . . *Thielavia basicola*, capable of attacking roots . . ." Here reference is made to parasitic organisms of the class *Thielavia basicola*.

GENERIC, OR GENERALIZED, USE OF CLASS WORDS

By use of the generic singular, or generalized use of a class word, is meant the use of a class word in a sense to include all the individuals of the class considered. A few examples follow: In the sentence, "The pine is a conifer," "pine" is used in the general sense to mean that all pines are cone bearing.

In the expression, "The protection function of the forest . . .," the word "forest" is used in the general sense; the meaning is that every forest in the world gives protection to the ground surface. But in the following sentence the term "forest" cannot be used in a generalized sense, because all forests are not implied, only those of many populous regions: "Robbed of the protective influence of forests, many of the most populous regions have become inhospitable and even uninhabitable wastes."

[8]See Webster's New International Dictionary, recent editions, especially under "Plural, X, Mass words."

Another example is given, one that pertains to deteriorated vegetation: "Man, in his aggressive exploitation of nature, risks upsetting and destroying favorable conditions . . . ." Here the generic singular "man" is correctly used in a general sense, because the statement holds true wherever men have exploited lands.

Compare the following two sentences: "The American Indian hunted," and "The American Indian hunted in Massachusetts." The first statement is true, because all American Indians hunted. The second statement cannot be true, because it implies that all American Indians hunted in Massachusetts.

It is not necessary to precede a generalized word with *the*, as, "Primitive *man* selected food plants." A generic singular may be preceded by *a* or *an*, as, "This explains why *a* class *word* is abstract . . . ," which is the same as saying ". . . why all class words are abstract . . . ." Commonly, a generalized noun preceded by *a* or *an* may express the thought more clearly than when preceded by *the*, for example, "*A* class *word* is abstract; its meaning is applied the same to all members of the class."

The use of *the* with a generalized noun is quite different from its uses as a definite article when it (1) indicates pre-eminence (as, the Nile), (2) when it designates something previously mentioned or implied (as, of the flowers, the roses grew best), and (3) when it particularizes, as, the cat [not dog] caught the mouse [not rat].

A COMMON FALLACY IN THOUGHT

Fundamentally, the misuse of class words commonly involves a fallacy in thought, called, according to Bowne,[9] the fallacy of the universal. A clear understanding of this fallacy calls for a clear understanding of general concepts, which are also called universal concepts and general notions.

All class terms, such as *Crotalus atrox*, *Quercus rubra* (species), *Drymaria* (genus), *Norfolk loam* (soil-type class), *Norfolk* (soil series), red oak, oak, soil, and dog, are names of universal concepts. Being a general concept, *Quercus rubra* (red oak), for example, embraces all individuals in this class; and *oak* includes all oaks. The general concept "*Quercus rubra*," or "red oak," implies those characteristics that distinguish red oaks from oaks of other kinds. Likewise, *oak* as a universal concept implies all the characteristics that are common to all oaks. Accordingly, *Quercus rubra* (red oak) merely stands for all red oaks, and oak represents all oaks.

Inasmuch as the meaning of a class word implies those characteristics that are common to all members of the class, the general concept indicated by the class name is created by definition. In this manner we create all general concepts, as *Crotalus atrox*, *Norfolk loam*, oak, and soil. This explains why a class word is abstract; it has only meaning, and hence it can never be the name of something that has materiality or individual character.

The fallacy of the universal consists in mistaking a universal concept for something that has material existence. To illustrate: In the expression, "germination of *Quercus alba*," *Quercus alba* has been

[9]BOWNE, B. P. Theory of Thought and Knowledge. New York. 1897.

mistaken for something that has physical existence, when it is merely an abstract class name.

Compare the following two sentences: (Wrong) "In this region *Calliandra* is common on *White House gravelly sandy loam.*" (Correct) "In this region calliandras are common on White House gravelly sandy loams." In the first sentence, *Calliandra* is the name of a genus of shrubs, and *White House gravelly sandy loam* is the name of a class of similar loams (soils). Hence in each case a general concept has been mistaken for something that has materiality.

Again, in the sentence, "The soil is a specific object in nature," the error is obvious. The general notion *soil* has been mistaken for something that is of the earth itself.

Difficulties in thought that result from confusion in the use of names of material things and of classes are similar to those that led early philosophers to much dispute between realism and nominalism, that is, whether individual objects or general concepts had actual reality. But that problem of early dispute has long been settled. Modern thought recognizes a wide difference between specific and class words. For example, there is a wide logical difference between the term "red oaks" and the word "*Quercus rubra*" (red oak), and between dogs (things) and dog (general concept). The one term names material objects, whereas the other names a universal concept. Bowne has suggested a way to avoid fallacies of the universal: When writing, keep specific things and specific names in mind.

A question may be raised regarding the names of species. Are such names the names of individual objects? From the way the term "species" is commonly misused, one might be led to answer this question in the affirmative. Briefly, let us look into this matter.

According to standard dictionaries, the term "species" is given the following meanings:

In logic. A group or class of individuals that have common attributes and that are designated by a common name. For example, *white* may mean a group of white or near-white individuals; as in chess, white means one of two sets each of eight pieces and eight pawns, and may represent the player who has them.

In biology. A class, or group of plants or animals that possess in common one or more characteristics that distinguish them from other groups of similar plants or animals.

The term "genus" also means class or group. In scientific soil classification, type as class corresponds to species in biology; and series corresponds to genus. The terms "species," "genus," "soil type," and "soil series" are not collective nouns. A plant species may include innumerable individual plants in various parts of a country or of the world. Thus *Quercus rubra*, for example, is the name of a class of oaks. The individuals of this group are similar—that is, they have in common certain characteristics that distinguish them from all other oaks in the world. By the same token, *Chester loam*, for example, is the name of a group of similar soils. This class name (suggesting characteristics common to all individuals of this class) identifies all soils that have *Chester loam* features.

The conclusion with reference to species is that the name of a species, whether in logic or biology, is the name of a class of similar individuals. Thus the name of a species is abstract, and it does not name anything that has individual character or materiality.

As pertaining to the use of universal concepts, they need careful watching, especially those that are designated by common class names, such as *soil* and *mouse*. Moreover, one should guard against the excessive use of *the*. One is prone to generalize and say, for example, "the soil" and "the mouse." The use of collective nouns also needs careful watching, likewise those nouns that have singular forms but which are plural. Shall one say, for example, "A good stand of aspen" or "A good stand of aspens"? The meaning of the term "stand" determines. As used here, "stand" refers to the number and distribution of plants growing on a unit of area. Hence one should say, "A good stand of aspens." But one may say, "A good stand of cotton," and "A good stand of timber." (The terms "cotton" and "timber" are collective.) Many of the errors that result from the careless use of class terms and of words that accompany them may be regarded as thought monstrosities; for example, "The mouse is an abundant population in some places."

OTHER POINTS PERTAINING TO CLASS WORDS

Attention is called to two other problems that pertain to the use of class words, *viz.*, the adjective use of the names of genera and other classes, and the singular meaning of all class names.

One may wish to use the name of a genus or of a higher class to modify the term "plants," for example, when there is no common name. When this is done, it concerns the plants of that particular class, and should be written, for example, "many *Drymaria* plants." But "many drymarias" is also an approved form. By the same token, one should write Chester soils, Chernozem soils, and Podzol soils; but Chester loams, chernozems, and podzols.

Ordinary adjectives and particularly those words that are appended to the names of genera are commonly used to designate plants or animals of particular species. To illustrate: Black walnuts (trees of the species *Juglans nigra*); white oak (of the species *Quercus alba*); ponderosa pines (of the species *Pinus ponderosa*); and Rothrock grama (grass of the species *Bouteloua rothrockii*).

Class names of species and genera are always singular, whereas the names of classes of higher categories in the various scientific classifications may have either the plural or the singular form. But in each case the meaning of a class word must be singular, owing to the fact that the meaning is applied identically to all the individuals represented. To illustrate: *Beta vulgaria* (sing. form), *Citrus* (sing.), *Miami loam* (sing.), Leguminosae (pl. form), Protozoa (pl.), Chernozem (sing.), and Podzol (sing.). The name "Leguminosae" stands for all plants of that class, but its meaning must be identical for each leguminous plant. Hence, the word "Leguminosae," although plural (Latin) form, names a general concept whose meaning is the same for each member of the class.

NOTE

IMPROVED RASP FOR SECURING PULP FROM SUGAR BEETS FOR ANALYSIS[1]

FOR determination of sucrose percentage and apparent purity coefficient, finely-divided pulp is rasped from the sugar beet root commonly by a disk rasp. In the method followed at certain factories and at the field stations of the Division of Sugar Plant Investigations, the washed or cleaned sample of roots is weighed and then each root of the sample is split approximately into halves by a saw or knife. One set of half roots is rasped to secure a composite pulp sample, the other set of half roots being discarded. In practice, the half beets from which pulp is to be rasped are placed longitudinally on a belt

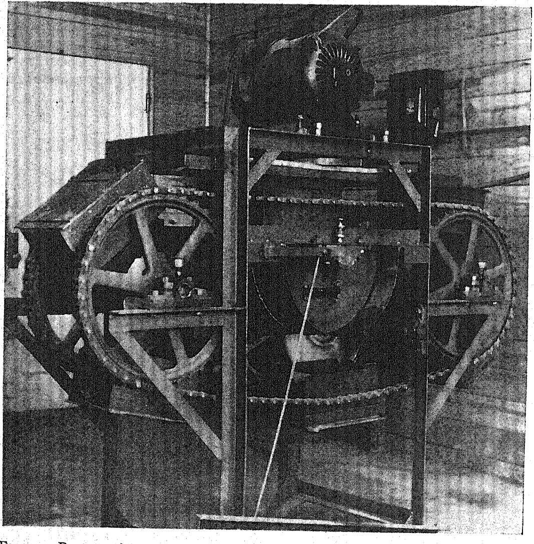

FIG. 1.—Beet rasping machine. The disk rasp carried on the central shaft cuts the pulp from the beet roots carried over it in the carrier boxes. The foot lever lowers a scoop holder to permit the removal of the scoop which contains the composite pulp sample. (Photographed by Mr. E. E. Patton of the Farmers & Manufacturers Beet Sugar Association).

[1]Cooperative investigations with the Michigan Agricultural Experiment Station.

studded with sharp points to hold them firmly. The belt then carries the half roots to the rapidly revolving disk rasp which cuts a radial sector from crown to tip of each, the pulp being thrown onto a wide semicircular band.

The basic idea embodied in the machine[2] which has been devised is that the whole sugar beet roots comprising the sample, after being washed or cleaned, are individually placed in carrier boxes which move over the disk rasp in such a manner that a radial sector is removed from each root. The machine has the advantage of making unnecessary the splitting of the roots of the sample, an operation which in sugar analysis procedure usually requires the time of one man. The whole roots after sampling commonly are accepted by the sugar factory, whereas half or quarter beets may be refused as not usable.

The machine as described (Fig. 1) has been constructed at the Michigan field station of the Division of Sugar Plant Investigations. Mechanical drawings showing construction of this machine are being prepared and copy may be had by anyone interested.—J. G. LILL, *Division of Sugar Plant Investigations, U. S. Dept. of Agriculture, East Lansing, Michigan.*

[2]The first machine of this type was developed by Mr. Ninegar of the Great Western Sugar Company. Machines based on the same idea were later built by Mr. H. L. Busch of the National Seed Company and Mr. C. E. Cormany of the Holly Sugar Corporation.

AGRONOMIC AFFAIRS

CROPS SECTION PROGRAM, 1940

TENTATIVE arrangements for the 1940 programs of the various Crops Sub-sections are announced by Dr. S. C. Salmon, Chairman of the Crops Section, as follows: A joint symposium with Soil Fertility and Soil Chemistry on "The Relation of Soil Type and Soil Treatment to Quality and Composition of Crops," under the leadership of Dr. W. H. Metzger for Soils and Dr. C. J. Willard for Crops; a symposium on weed control, under the leadership of Dr. C. J. Willard; four symposia on various phases of breeding sorghums and small grains, under the general leadership of Dr. P. C. Mangelsdorf, with Dr. K. S. Quisenberry arranging for those relating to wheat; Grassland Agriculture, under the leadership of Dr. O. S. Aamodt.

It is anticipated that there will be held a general crops session for all sub-sections, with a brief program and a business meeting. Several sessions are being held open for volunteer papers and it is urged that all who contemplate the presentation of such papers submit titles to the Chairman of the Section at an early date. It is probable, also, that provision will be made for one or more informal round-table discussions relating to subjects of interest to small groups.

THE 1939 PROCEEDINGS OF THE SOIL SCIENCE SOCIETY

FOLLOWING regretable delays, some of which were beyond the control of the Editor, proofs are now beginning to go out to the authors on the 1939 volume of Proceedings of the Soil Science Society. Part of the delay has been due to the decision to print the volume by letterpress instead of using the offset process employed heretofore. Before arriving at this decision, it was necessary to have all copy in hand in order to arrive at a reasonable close estimate of cost of publication. In the earlier volumes where this question did not enter in, it was possible to begin work as soon as copy was received regardless of whether the complete manuscript for all Sections was available.

Most of the type has been set on Volume 4 and it is confidently expected that the volume will now move along rapidly to completion. We hope that the improved appearance of the volume will compensate, to some extent at least, for the delay experienced this year. If this method of publication proves satisfactory, it will be possible to move Volume 5 much more expeditiously.

ALFALFA IMPROVEMENT CONFERENCE

THE Eighth Alfalfa Improvement Conference will be held at Fort Collins, Colorado, July 8 and 9.

Workers in charge of the experiments at the Scotts Bluff Field Station, Mitchell, Nebraska, will be available July 6 to explain the research program at that station.

MEETING OF THE WESTERN BRANCH OF THE SOCIETY

THE Western Branch of the American Society of Agronomy will hold its annual meeting for 1940 on July 11, 12, and 13, at Logan, Utah. These dates were chosen to harmonize with the regional alfalfa

conference to be held at Fort Collins, Colorado, just prior to the Branch meetings and the regional grass conference to be held in this area immediately after the Branch meetings.

Response to a questionaire sent out some time ago indicated that very interesting papers will be presented and a good attendance is expected.

BIBLIOGRAPHY OF LITERATURE ON POTASH AS A PLANT NUTRIENT

UNDER the above title the American Potash Institute, Inc., Washington, D. C., has issued the first of a series of lists of references to the literature on the subject. The first contribution covers literature reviewed from July 1 to September 30, 1939. The material is presented in three sections, namely, by crops, by subject under potash, and under soils, and is supplemented with a subject and author index.

According to a notice accompanying the first number, it is proposed to issue several numbers of the Bibliography per year to be sent gratis to those requesting it.

CHANGE IN DATE OF SUMMER MEETING OF CORN BELT SECTION

THE summer field meeting of the Corn Belt Section of the American Society of Agronomy is now scheduled for September 9 and 10 at Iowa State College instead of 4, 5, and 6, as reported in the April issue of the Journal. It was determined that this change is desirable in the interest of the expanded Grassland Conference program, scheduled for the campus at Ames on September 11.

Inspection of work at the Agronomy Farm south of the campus, will start at 1:30 on Monday. A dinner and short program at 6:30 will be followed by group conferences at 8:00, with special emphasis on plot design and statistical analyses. Tuesday at 8:00 field inspections will be continued and at 11:00 groups will leave Ames to see work in other parts of the state.

The Regional Grassland Conference program will get underway at 9:30 on the 11th, continuing through the afternoon and evening. The conference of technical workers, as carried out at the Ohio meeting last year, has been expanded for this year with agricultural leaders in all related fields invited to participate. The conference is sponsored by the Pasture Committee of the Agronomy Society and by the Association of North Central Agricultural Experiment Station Directors.

NEWS ITEMS

FRED K. CRANDALL, Assistant Agronomist at the Rhode Island Agricultural Experiment Station, died on May 31.

A JOINT meeting of the Florida State Florists Association and of the Soil Science Society of Florida was held at the University of Florida, May 28, 29, and 30, with Dr. S. A. Waksman as the principal speaker on the general program. Symposia were also held on soil organic matter and micro-elements in Florida agriculture. Dr. Michael Peech of the Lake Alfred Substation was elected president for the coming year and Dr. R. V. Allison, head of the Soils Department at the University of Florida, the retiring president, was named secretary-treasurer.

SURPLUS copies of the TRANSACTIONS of the Third Commission of the International Society of Soil Science have been transferred to Geneva, N. Y., and placed in storage with other soils and agronomic publications distributed by the Soil Science Society and the American Society of Agronomy. Volume A of the TRANSACTIONS contains the formal papers given at the New Brunswick, N. J., meeting, while Volume B contains the program, list of participants, a report of the discussion of the papers, and other incidental material. Both volumes are paper bound and are available for $2.00 for the two volumes, post paid.

THE CANADIAN SEED GROWERS' ASSOCIATION and the Canadian Society of Technical Agriculturists met in joint sessions at the University of Manitoba, June 17 to 22.

THE WORKS PROGRESS ADMINISTRATION has issued a limited edition of Volume III of its "Index to Research Projects" undertaken under the auspices of the Administration.

THE IMPERIAL BUREAU OF PASTURES AND FORAGE CROPS at Aberystwyth, Great Britain, has issued the following bulletins in its Herbage Publication Series: Bulletin 27, "The Control of Weeds," edited by R. O. Whyte, 168 pages, illustrated, price 7s. 6d. Bulletin 28, "Technique of Grassland Experimentation in Scandinavia and Finland," 52 pages, illustrated, price 2s. 6d. Bulletin 29, "Grassland Investigations in Australia," 107 pages, price 5s.